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Title: The Biggest Fool Thing

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“(The atomic bomb) is

the biggest fool thing

we have ever done…. The bomb will never go off, and I speak as an expert in explosives.”

Adm. William Leahy, USN
to President Truman, 1945

An Overview of
Nuclear Explosives Safety
by Paul D. Peterson (W-NES)

This document has been reviewed and determined to be **UNCLASSIFIED** by:
Paul D. Peterson, Ph.D.
Program Director 4

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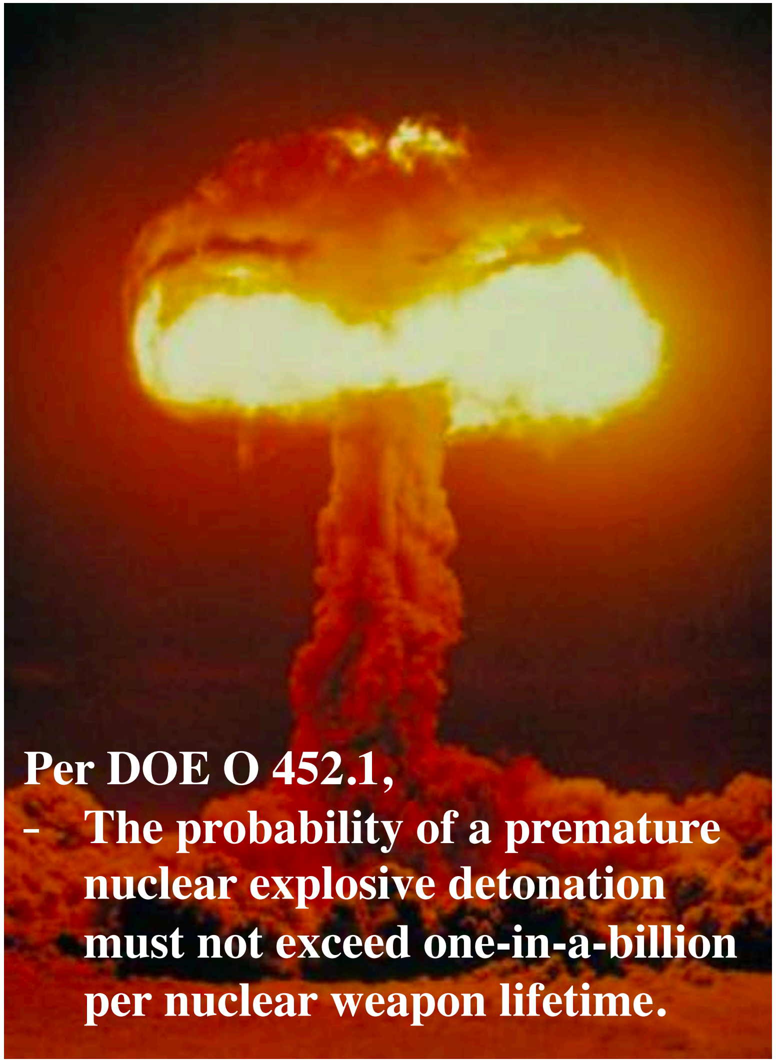
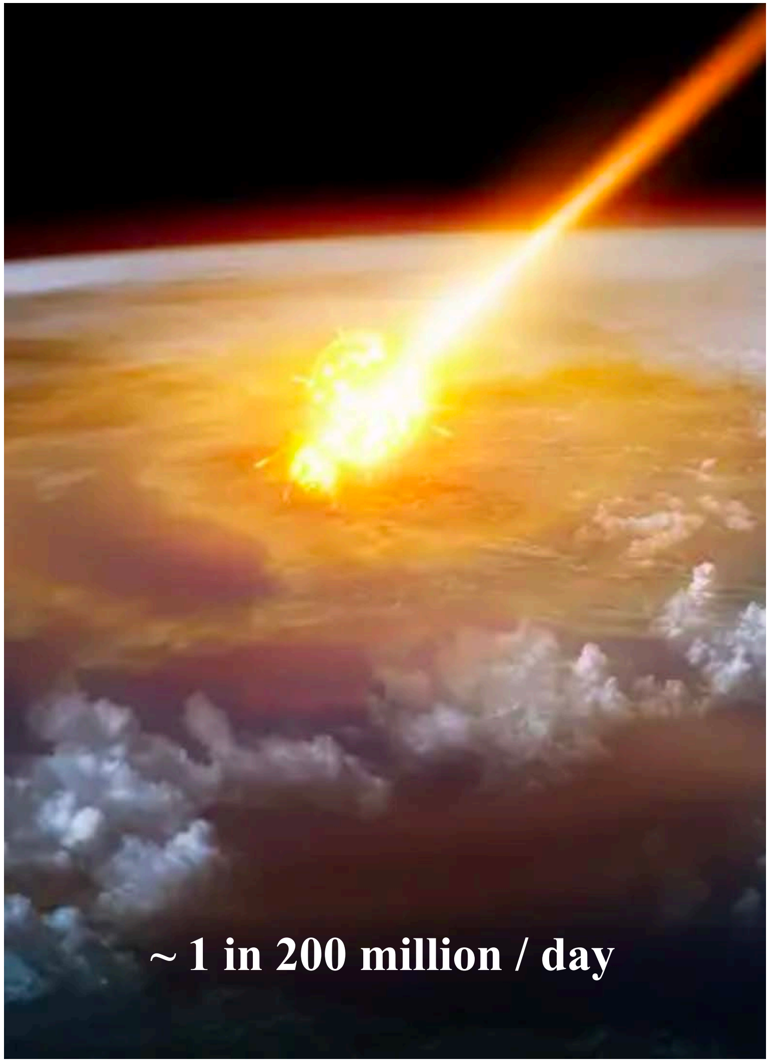
ABSTRACT

This presentation provides an overview of Nuclear Explosives Safety for a W/Q/E Division WebeX. It includes an overview of how detonators and high explosives are considered as part of Nuclear Explosives Safety. Several accidents involving High Explosives are also discussed. This presentation was adapted from LA-CP-16-20438.

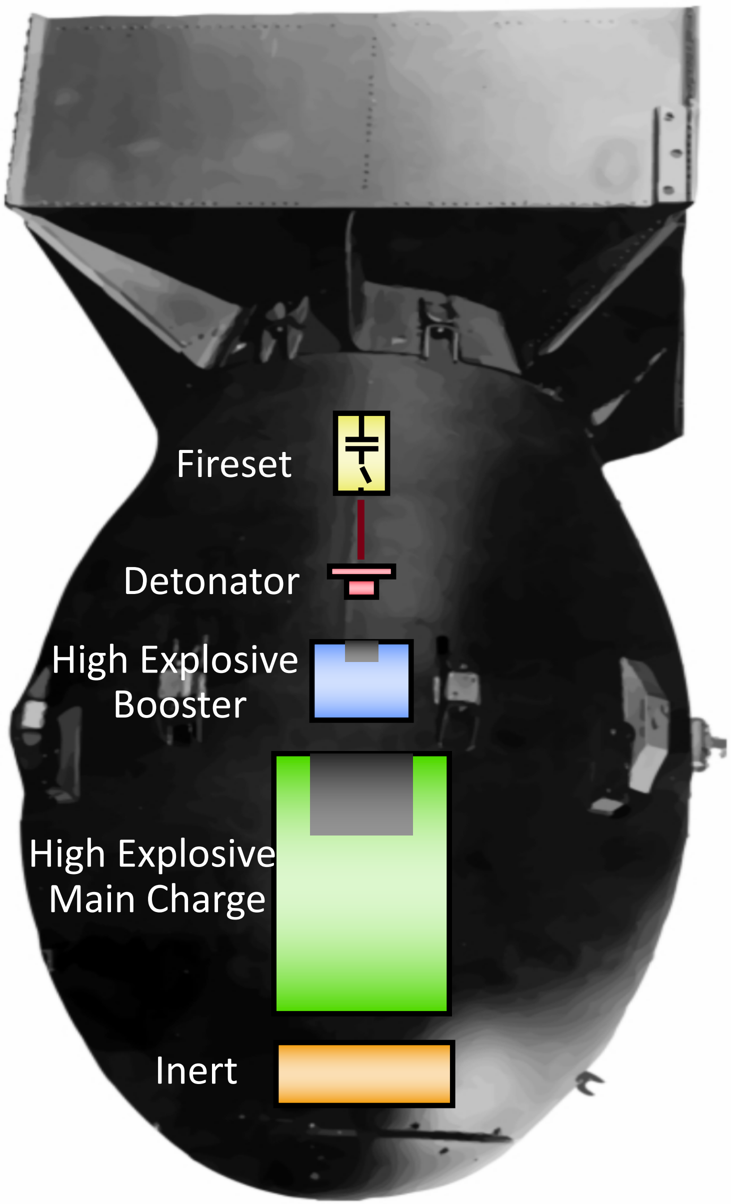
Nuclear Explosive Safety

Mission – Prevent Inadvertent Nuclear Detonation





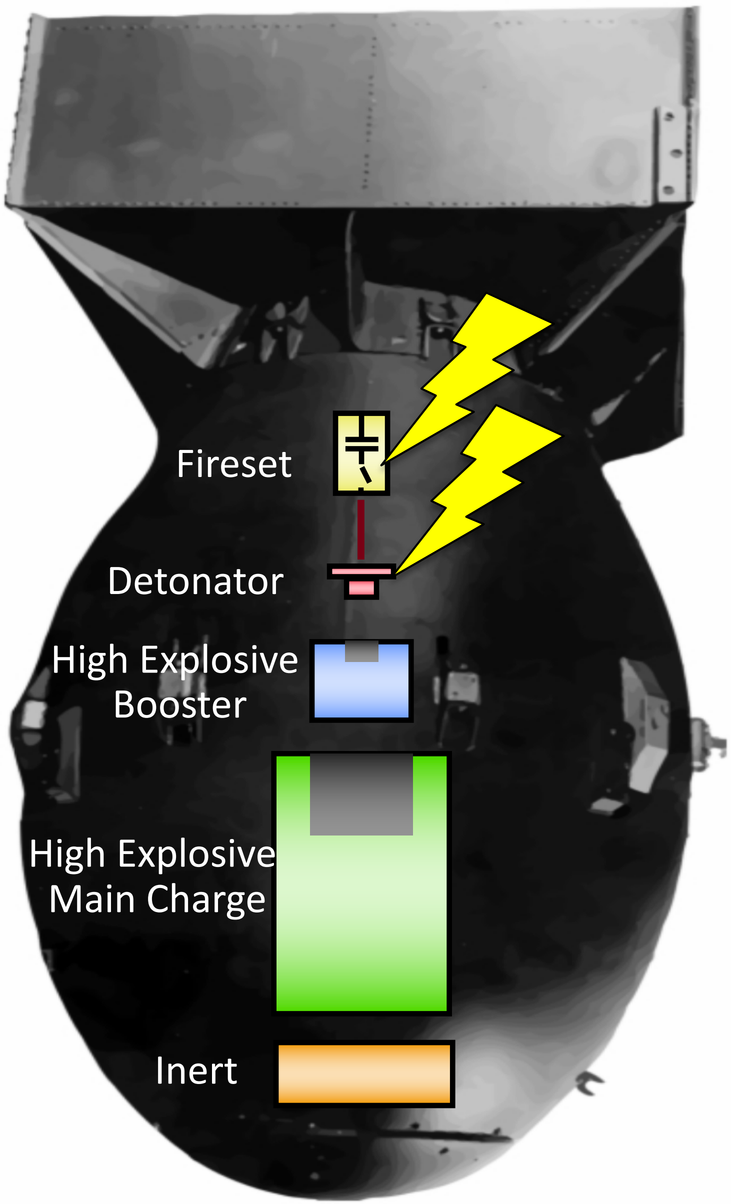
How Nuclear Weapons Work



- Firesets provide the initial electrical energy to a detonator
- Detonators provide the first detonation
  - Matched to initiate the booster (when functioned normally)
- Boosters provide a stronger detonation
  - Matched to initiate the Main Charge (when functioned normally)
- Main Charge detonation provides the vast majority of the energy and power
  - Size and shape are designed to move the inert in a specific direction and velocity
- The Inert is moved or damaged by design
  - Rock or soil in a mining bore hole
  - Steel case on a bomb or grenade
  - Nuclear material in an A-bomb

How Nuclear Weapons Work

. . . when we don't want them to!



The fireset and detonator are susceptible to electrical insults (lightning, AC, DC, ESD)

	Hot Wire	EBW	Slapper
Current: Threshold	1 Amp	200 Amps	2000 Amps
Current: Operating	5 Amps	500 Amps	3000 Amps
Voltage: Threshold	20 Volts	500 Volts	1500 Volts
Energy: Threshold	0.2 Joule	0.2 Joule	0.2 Joule
Power: Threshold	1 Watt	100,000 Watts	3,000,000 Watts
Function Time:	1 millisecond	1 microsecond	0.1 microsecond

Numbers above are typical and not meant to represent actual devices.

How Nuclear Weapons Work

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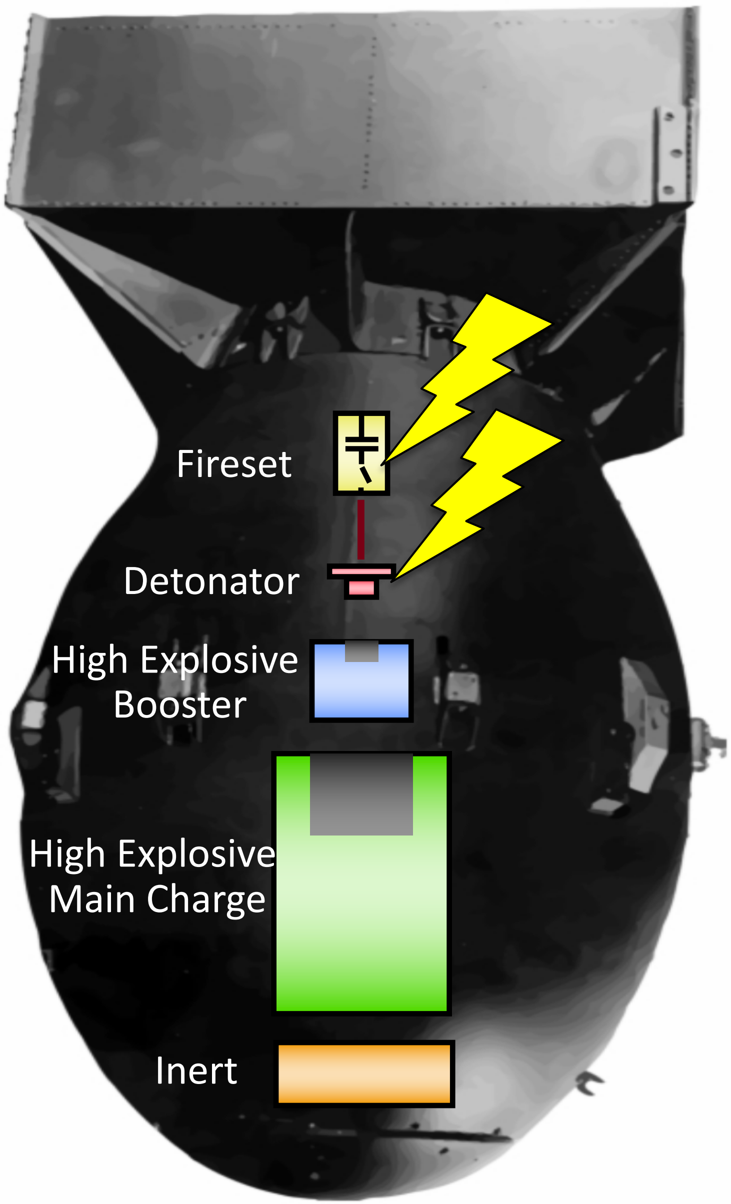

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	Hot Wire	EBW	Slapper
Current: Threshold	1 Amp	200 Amps	2000 Amps
Cur Ope			
Volt Thre			
Ene Thre			
Pow Thre			
Function Time:	1 millisecond	1 microsecond	0.1 microsecond

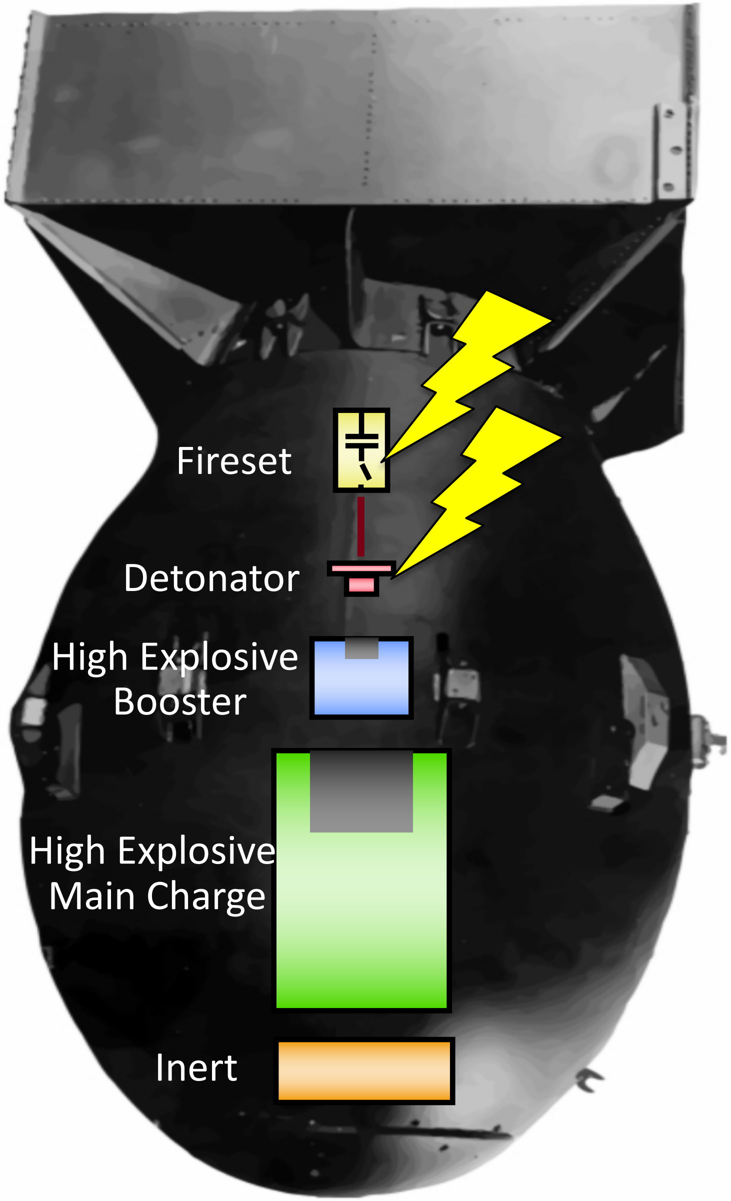
What will lightning do?

	50% (Median)	99% (Extreme)
Peak Current (kA)	20	200
Time to Peak (μs)	2 – 3	15
Rise Rate (kA/μs)	20	400

The odds of you becoming a lightning victim in the U.S. in any one year is 1 in 700,000. The odds of being struck in your lifetime is 1 in 3,000. (per National Geographic 2005)

How Nuclear Weapons Work

. . . when we don’t want them to!



The fireset and detonator are susceptible to

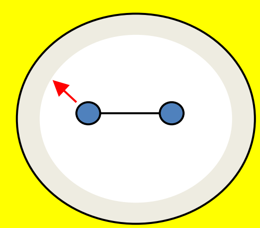
What will Human ESD do?

	SNL Standard Man	SNL Severe Man
Capacitance	**20 pF**	**200 pF**
Voltage	**20,000 V**	**25,000 V**

Voltage: Threshold	20 Volts	500 Volts	1,500 Volts

Electrostatic Discharge?

Human ESD
Furniture ESD (worse than Human)
Repeated Insults
Pin-to-Case Arcing

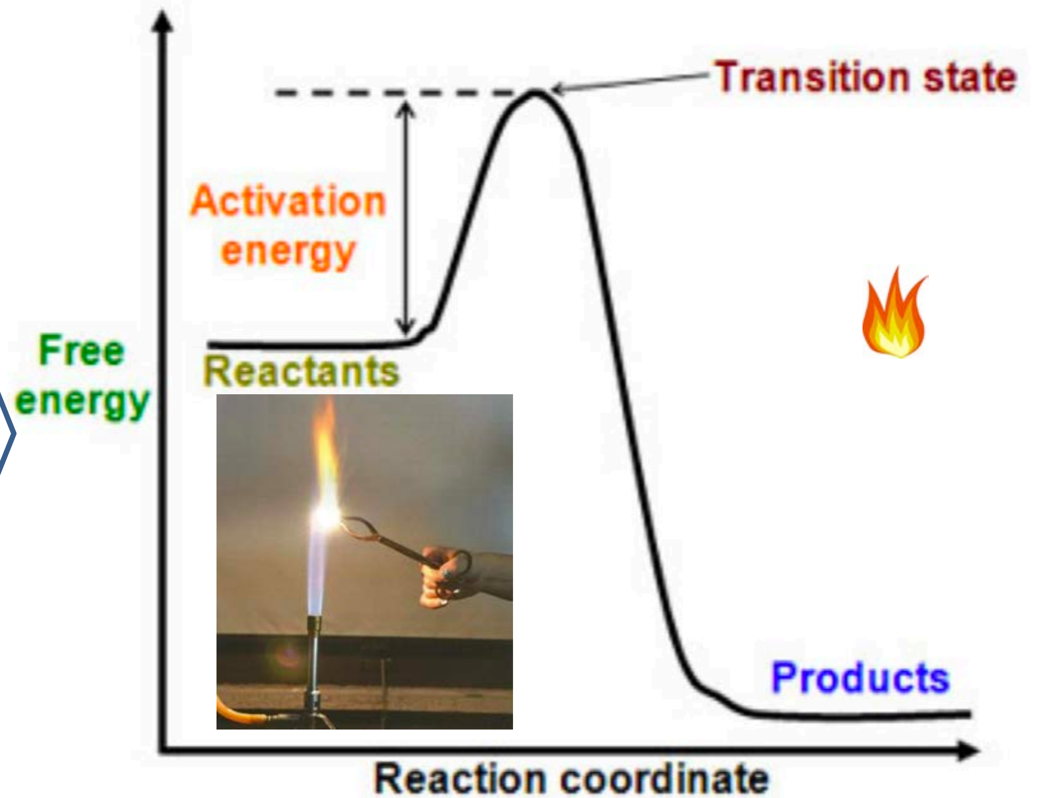


How Nuclear Weapons Work

. . . when we don't want them to!

EXPLOSIVE – A reactive chemical substance that contains a great amount of potential energy, and which can release that energy in a rapid expansion of mass motion (work), pressure, heat, light, and sound.

Detonators, Boosters, and Main Charges are all High Explosive (HE) components.



How Nuclear Weapons Work

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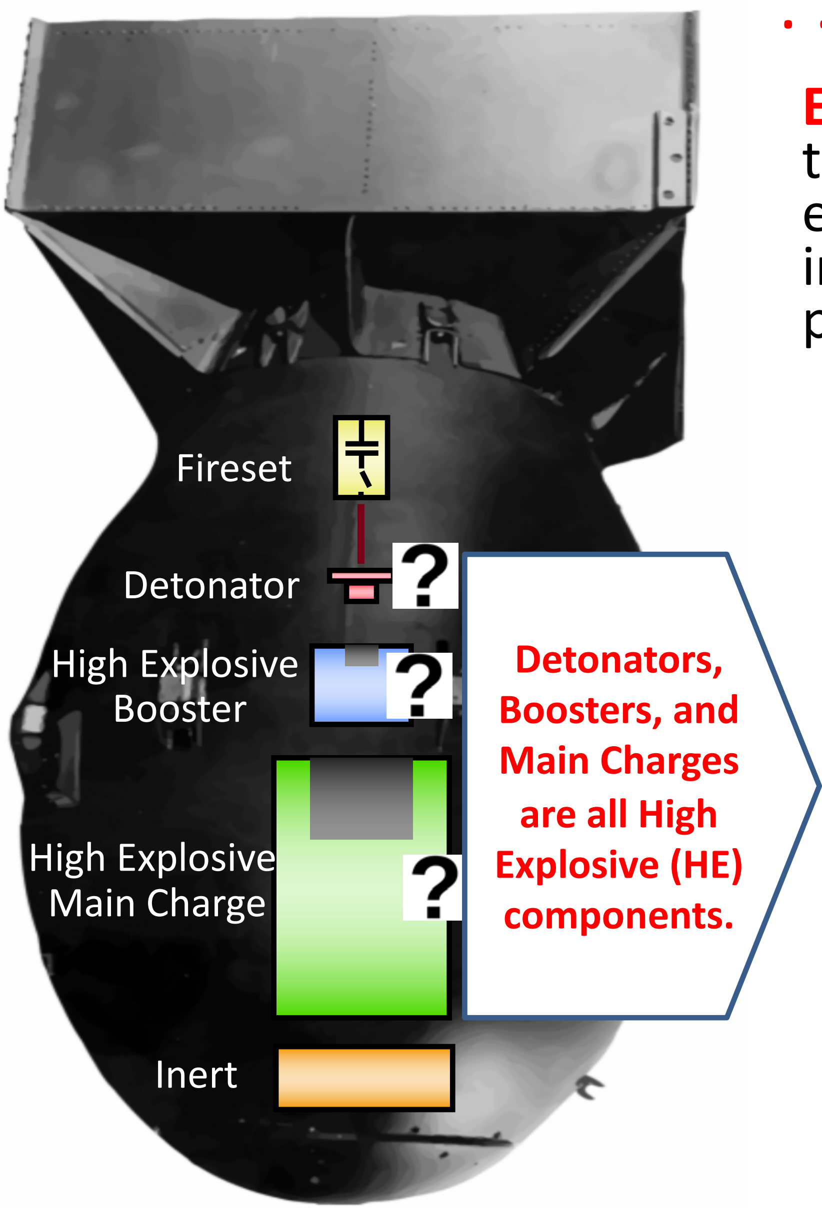


EXPLOSIVE – A reactive chemical substance that contains a great amount of potential energy, and which can release that energy in a rapid expansion of mass motion (work), pressure, heat, light, and sound.

$$\beta\text{-HMX} \longleftrightarrow \delta\text{-HMX}$$

$$\beta\text{-HMX} + \delta\text{-HMX} \xleftrightarrow{k_1} 2\ \delta\text{-HMX}$$

$$\delta\text{-HMX} \underset{k_{2b}}{\overset{k_{2a}}{\longleftrightarrow}} \text{g-HMX}$$

$$\textit{sublimation} \qquad a \underset{k_{2b}}{\overset{k_{2a}}{\longleftrightarrow}} b \qquad \textit{vaporization}$$

$$\delta\text{-HMX} \xrightarrow{k_{2b}} 4CH_2O + 2NO_2 + 3N_2$$

$$\delta\text{-HMX} \xrightarrow{k_{2a}} 4HCN + 3NO_2 + 2H_2O + (1/2)N_2$$

$$CH_2O + NO_2 \xleftrightarrow{k_3} CO_2 + H_2O + (1/2)N_2$$

$$HCN + M \xrightarrow{k_4} HNC + M$$

$$HNC + NO_2 \xrightarrow{k_{4a}} HNCO + NO$$

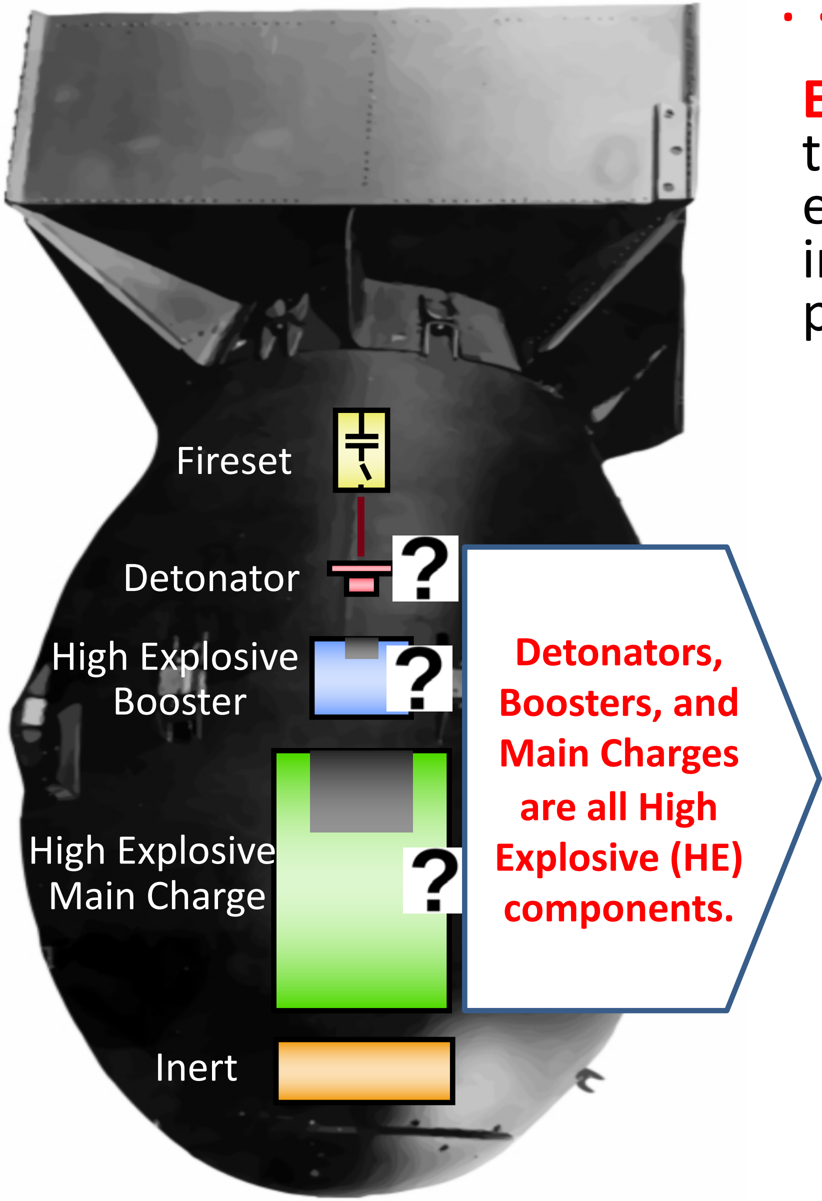
$$HNCO + NO_2 \xrightarrow{k_{4b}} H + N_2O + CO_2$$

$$2H + N_2O \xrightarrow{k_{4b}} H_2O + N_2$$

$$HNC + HCNO + 2NO \xrightarrow{k_{4b}} H_2O + 2CO + 2N_2$$

How Nuclear Weapons Work

. . . when we don't want them to!



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How Nuclear Weapons Work

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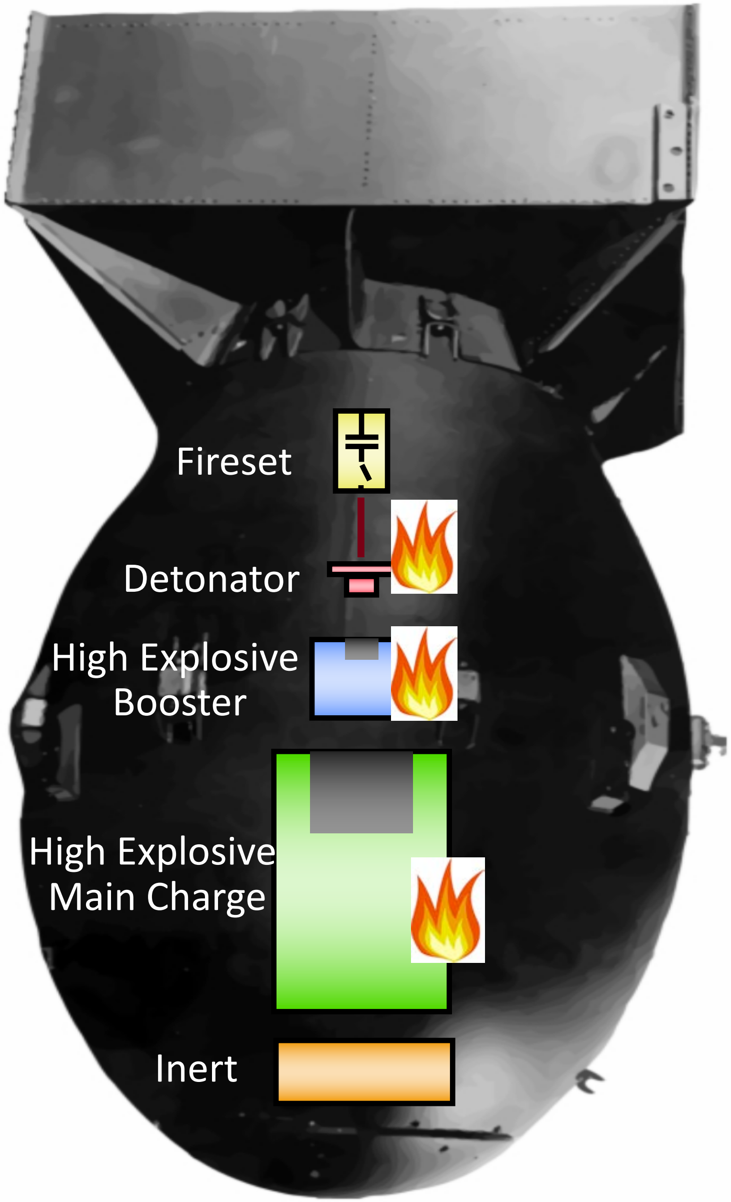


The detonator, booster, and main charge HE will react to thermal stimuli.

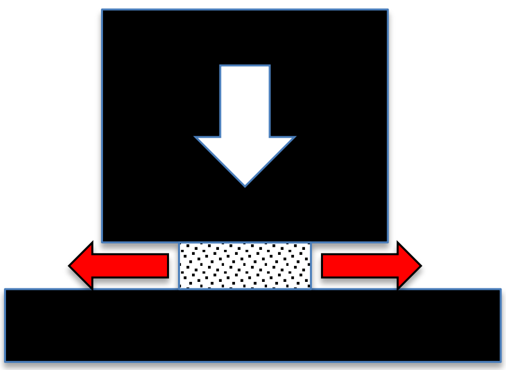
"A useful explosive material is, of course, stable under reasonable environmental conditions. It will neither release energy nor produce gas without some kind of <u>thermal stimulus</u>.

- W.L. Perry in <u>Non-shock Initiation of Explosives</u>

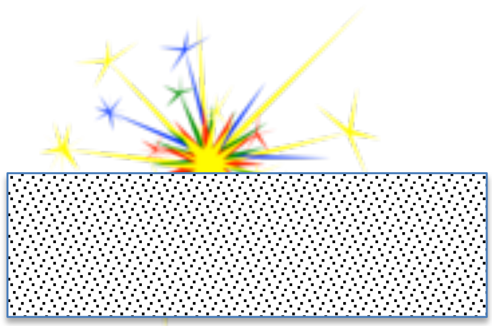
All insults are thermal!

"... impact, spark, friction, boundary heat, or shock. These processes raise the temperature of the explosive material, either in a localized volume, or thoughout its entire volume, to a point where the exothermic, gas-producing reaction becomes self-sustaining (ignition)."

- W.L. Perry in Non-shock Initiation of Explosives

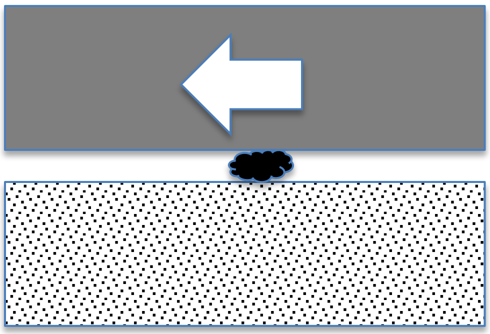


Impact (with pinch) generates heat due to visco-elastic plastic flow.



A pyrophoric spark will generate heat.

It is very difficult to couple electricity (electrical spark) directly to HE.



Grit-enhanced initiation is well known (skid test, pendulum test, Type 12 Drop Hammer).

It is very difficult to produce sufficient heat through clean HE-HE friction because the heated surface wears away.

All insults are thermal!

"**Impact** leads to localized heating when deformation becomes concentrated, where the material fails by cracking, or when the yield strength is exceeded and causes shear localization and concentration of energy along shear bands."

"**Friction** localizes heat between moving surfaces or at specific locations, where, for example, foreign matter (grit) becomes trapped between the surfaces."

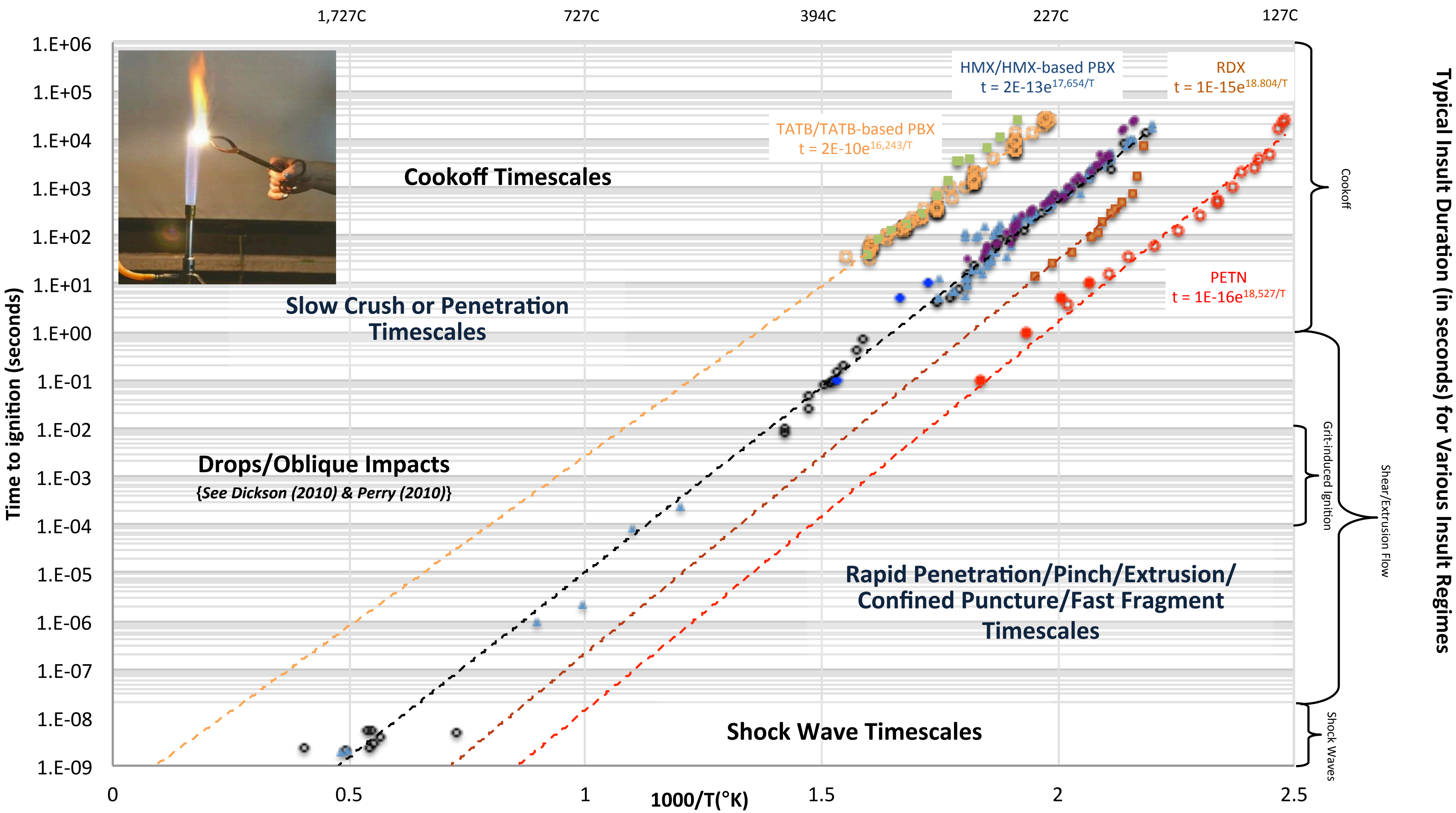
"**Shock waves** compress material along its leading edge and cause heat generation directly by adiabatic compression of the material itself, by collapsing void space, or by grain boundary interactions."

"**Boundary heat**, as the phrase implies, is heat applied to the outer surface of an explosive charge or its container,… ignition by this method is commonly called "cookoff"."

"The stimuli listed above all serve to raise the temperature of the explosive either within a volume small with respect to the charge (impact, spark, friction, shock) or globally (boundary heat). The specific ignition threshold is crossed when the rate of heat production (due to exothermic chemical reaction) in a volume exceeds the rate of heat removal from that volume (conductive or convective heat dissipation). . . ." (W.L. Perry in Non-shock Initiation of Explosives)

Ignition of HE requires time

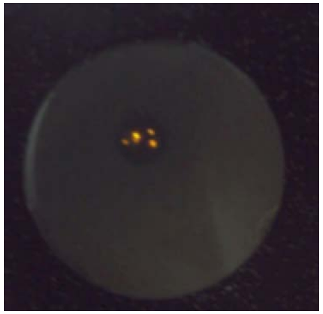
Time to Ignition of HE at a given Temperature



Ignition, Deflagration, Detonation, and DDT

What's the difference?

IGNITION (HOT SPOTS)



If a small volume of HE is heated it starts to exothermically decompose. The higher the temperature the faster the decomposition. The small volume heats surrounding material. If the reaction rate is too slow, the reaction will quench (stop). If the small volume produces heat faster than it can be transferred, it heats up, reaction rate increases, and the hot spot becomes self-sustaining.

DEFLAGRATION

The usually rapid and self-sustaining, but subsonic, chemical reaction between a fuel and an oxidizer which produces heat, light, and gaseous products. The violence of the reaction is dependent on confinement.

DETONATION

A rapid chemical reaction initiated by the heat accompanying a shock compression, which liberates sufficient energy before expansion occurs to sustain a shock wave. Differentiated from a deflagration by the propagation of the shock wave at supersonic speed.

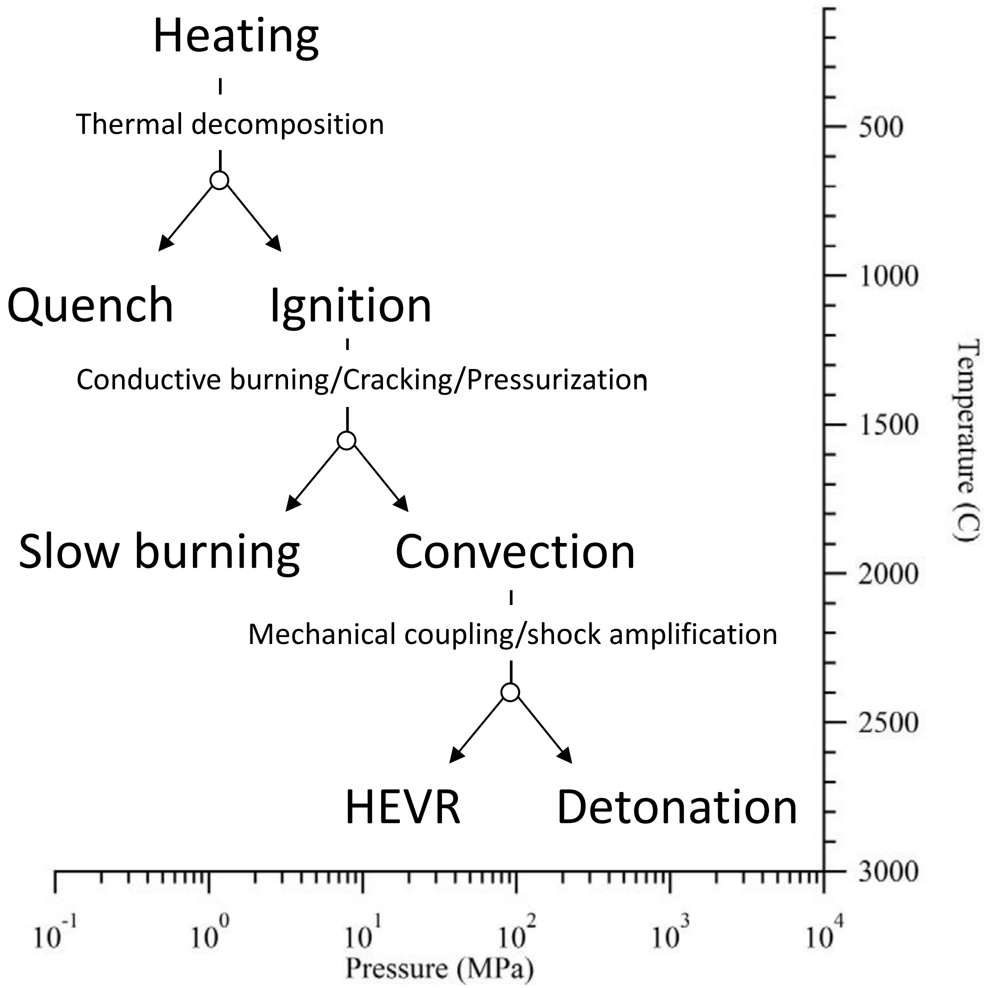
DEFLAGRATION TO DETONATION TRANSITION (DDT)

The change of chemical reaction from a rapid subsonic burn to a self-sustaining, supersonic shock wave.

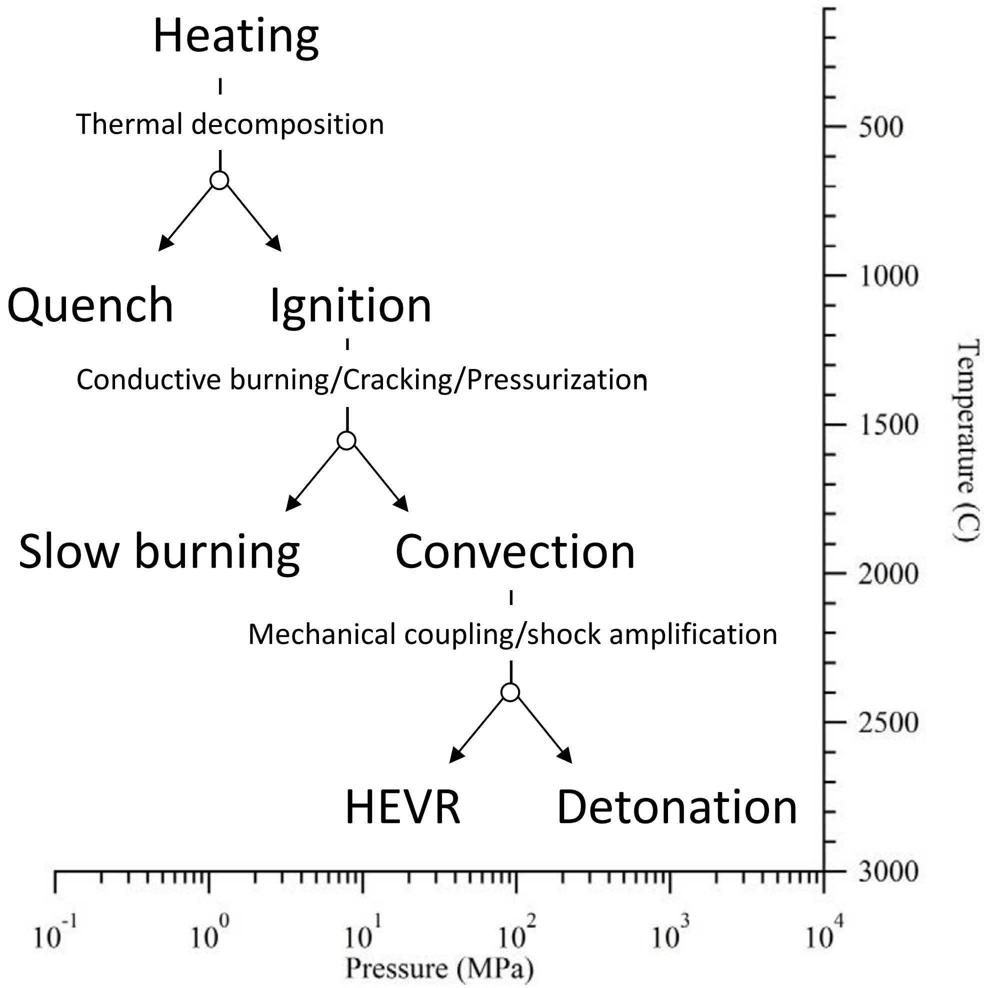
15

What happens if we accidently ignite the HE in the detonator, booster or main charge?

Ignition does not ensure detonation!



Pop Quiz



Heating
Thermal decomposition
Quench
Ignition
Conductive burning/Cracking/Pressurization
Slow burning
Convection
Mechanical coupling/shock amplification
HEVR
Detonation
500
1000
1500
2000
2500
3000
Temperature (C)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Pressure (MPa)

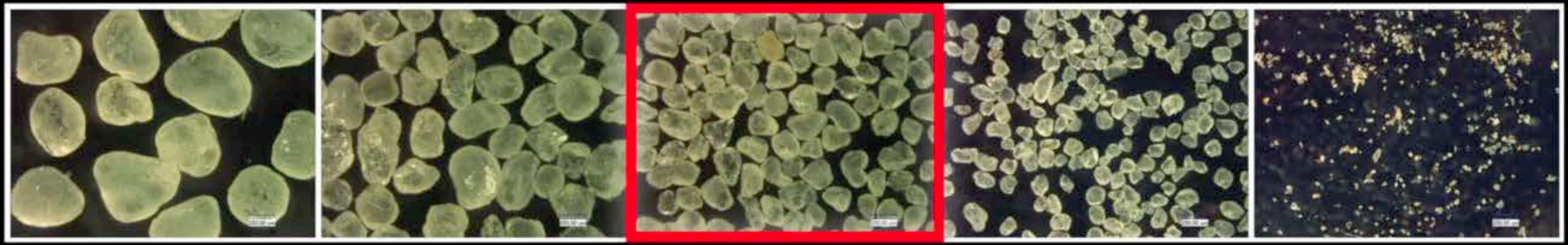
Skid Testing Drop 048A

Nominal Height:

Material: PBX 9501

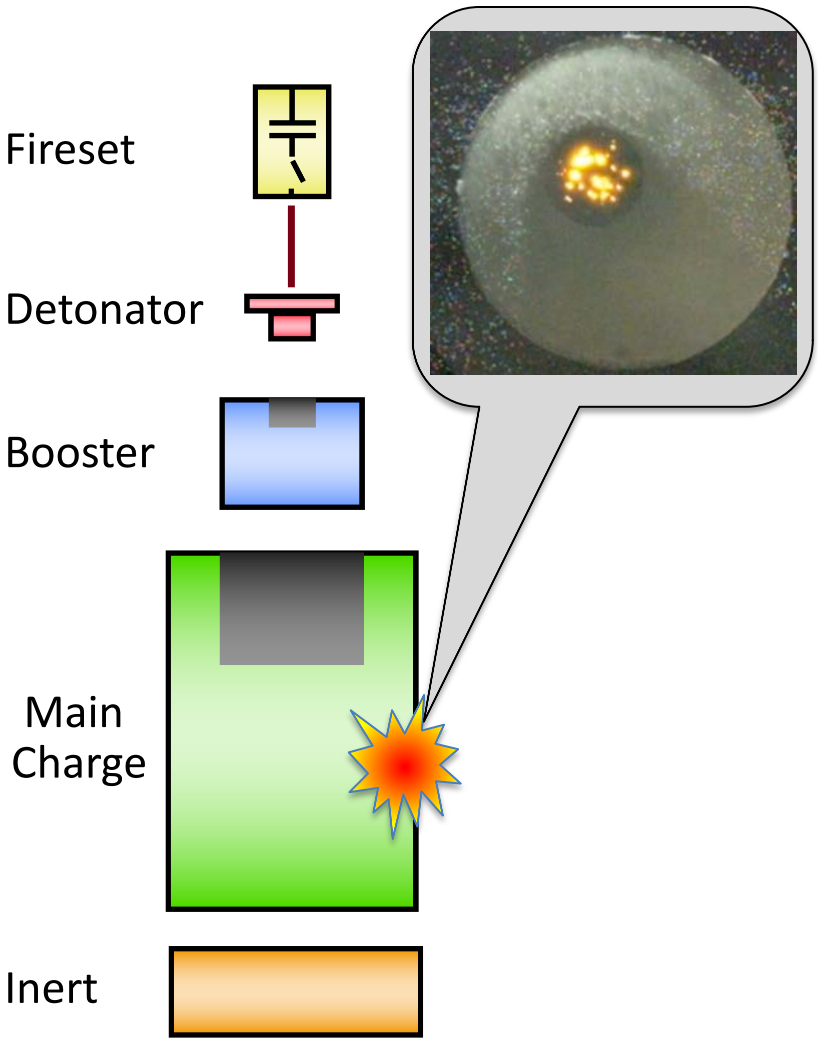
Impact Surface: glass

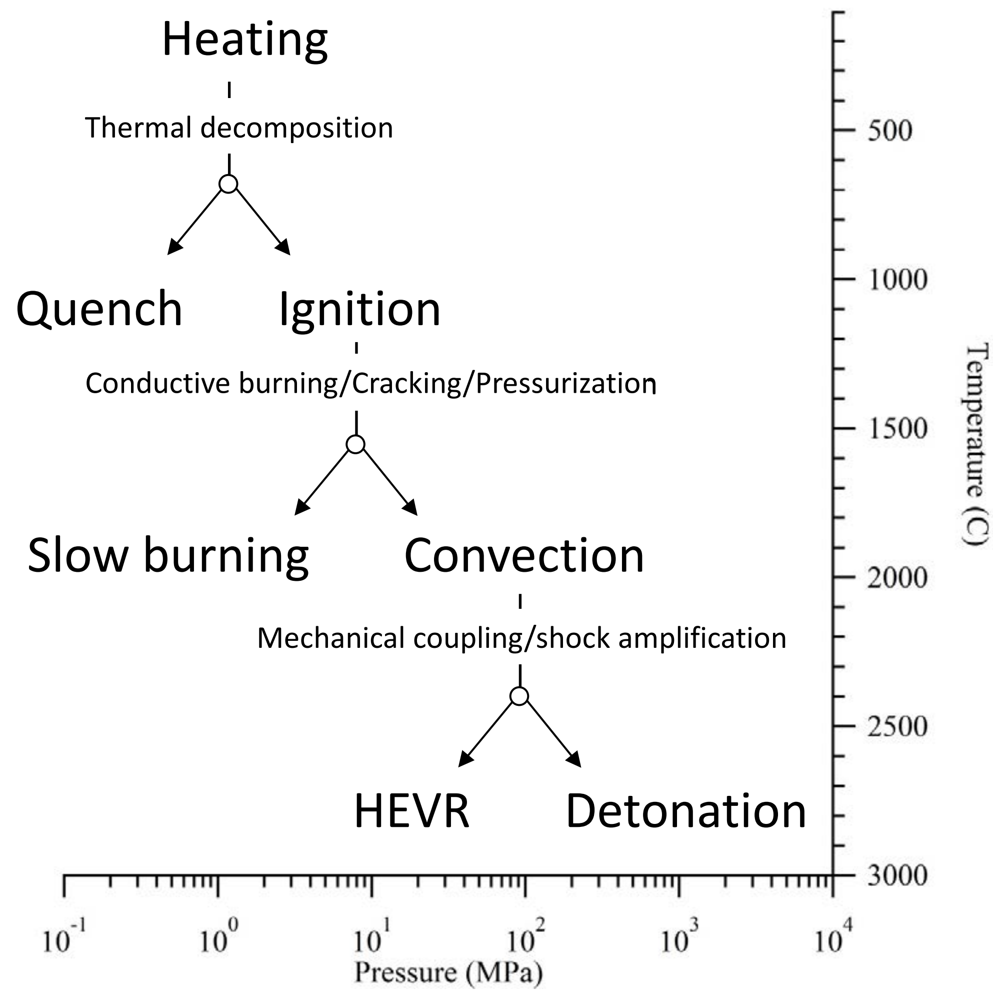
Grit: 150-250 micron dia.



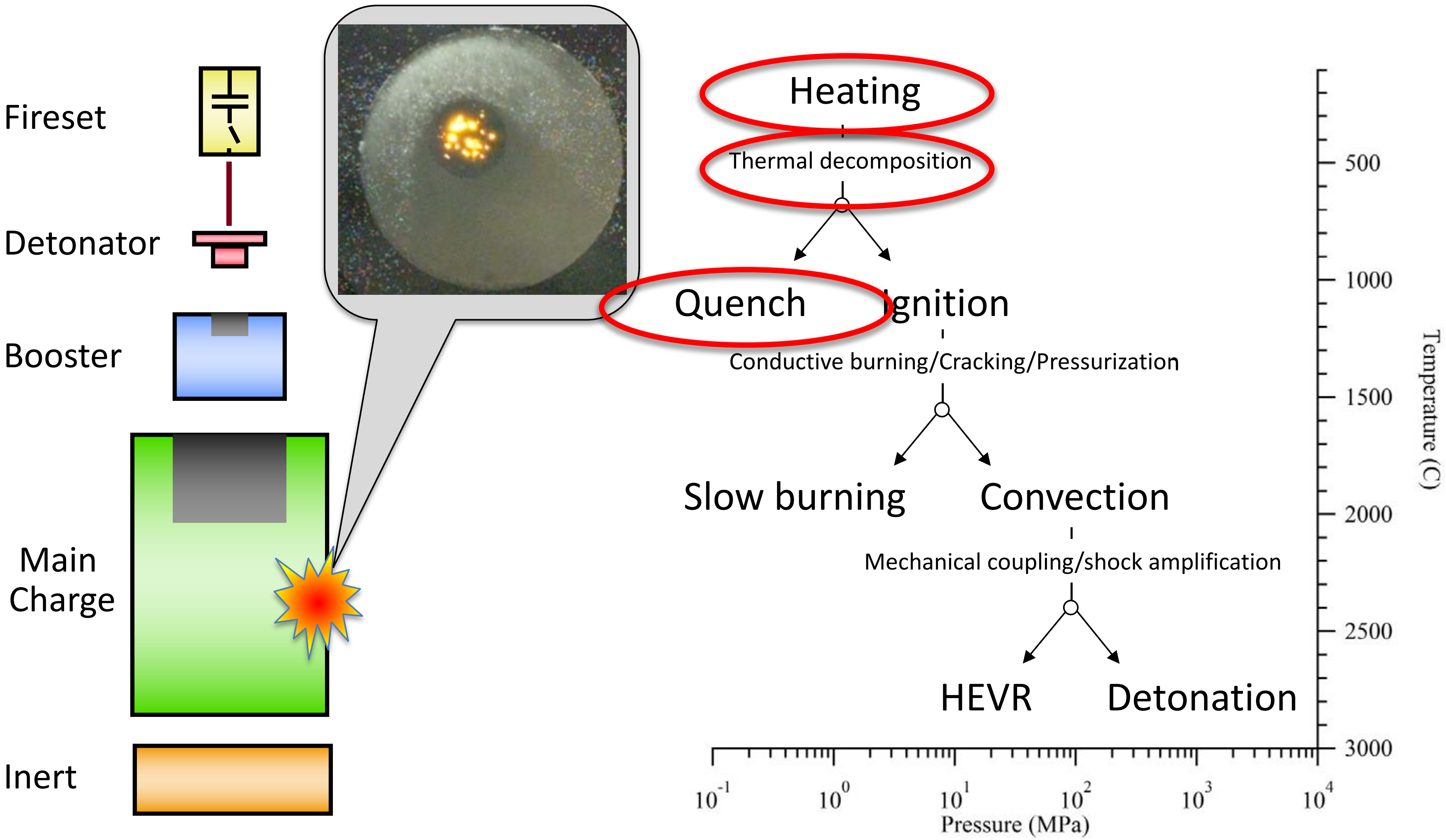
Notes: Random coverage. Example of intermediate violence response.
Ignition sites with growth and joining.

What happened in this test?



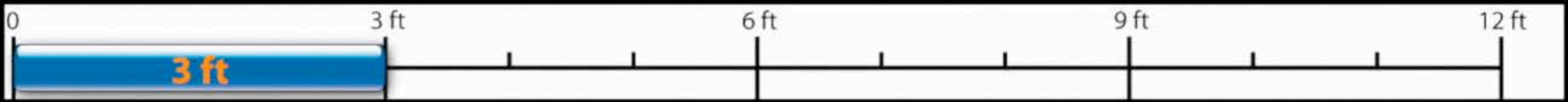


What happened in this test?



Skid Testing Drop 034A

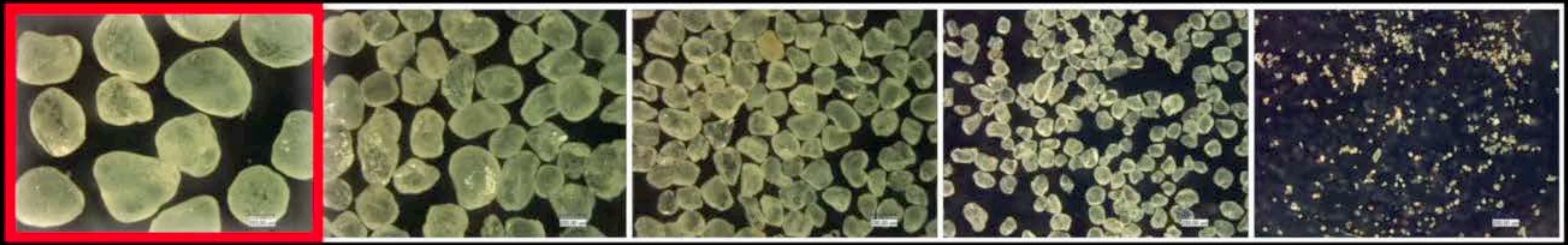
Nominal Height:



Material: PBX 9501

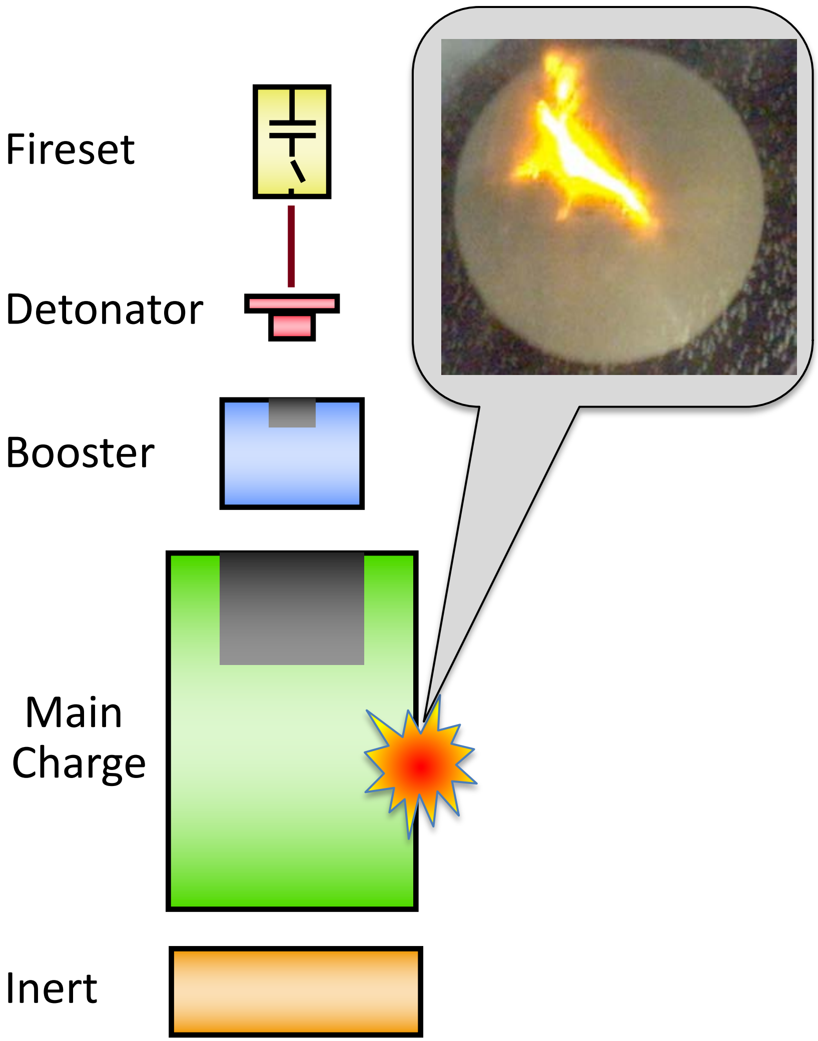
Impact Surface: glass

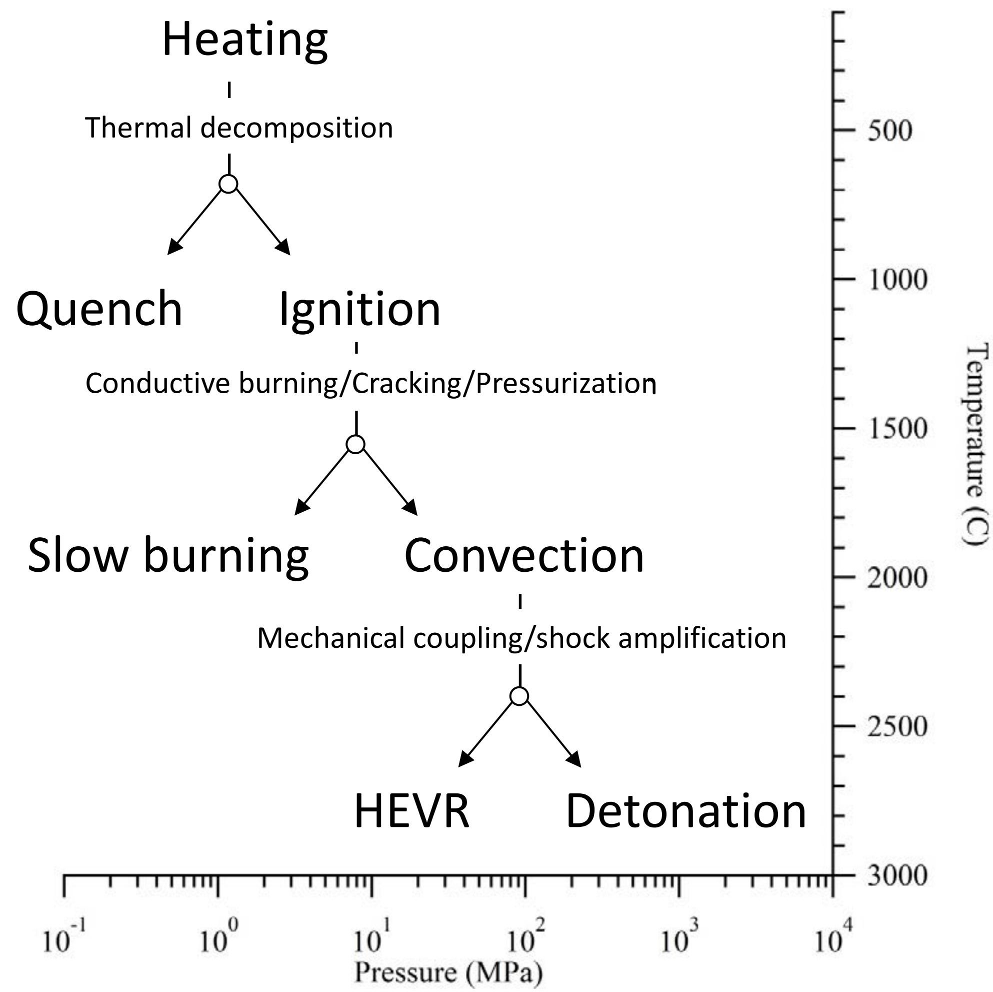
Grit: 500-1000 micron dia.



Notes: Random coverage. Example of intermediate violence response. Cracking with flame spread into cracks.

What happened in this test?





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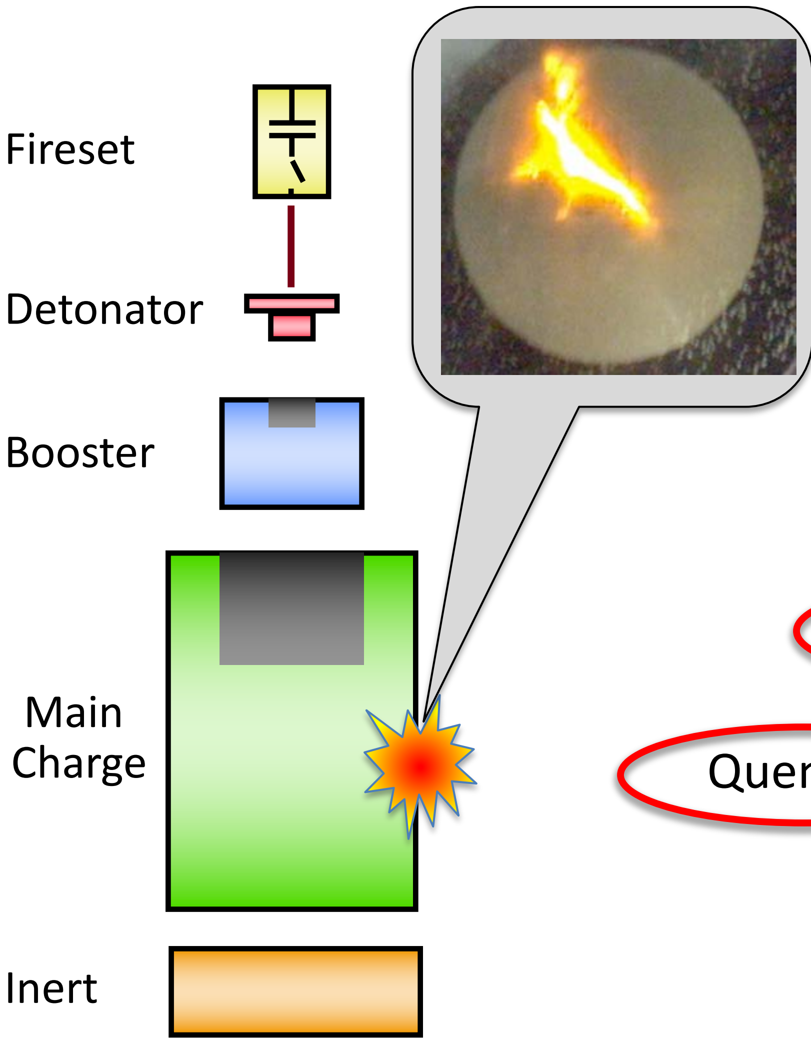
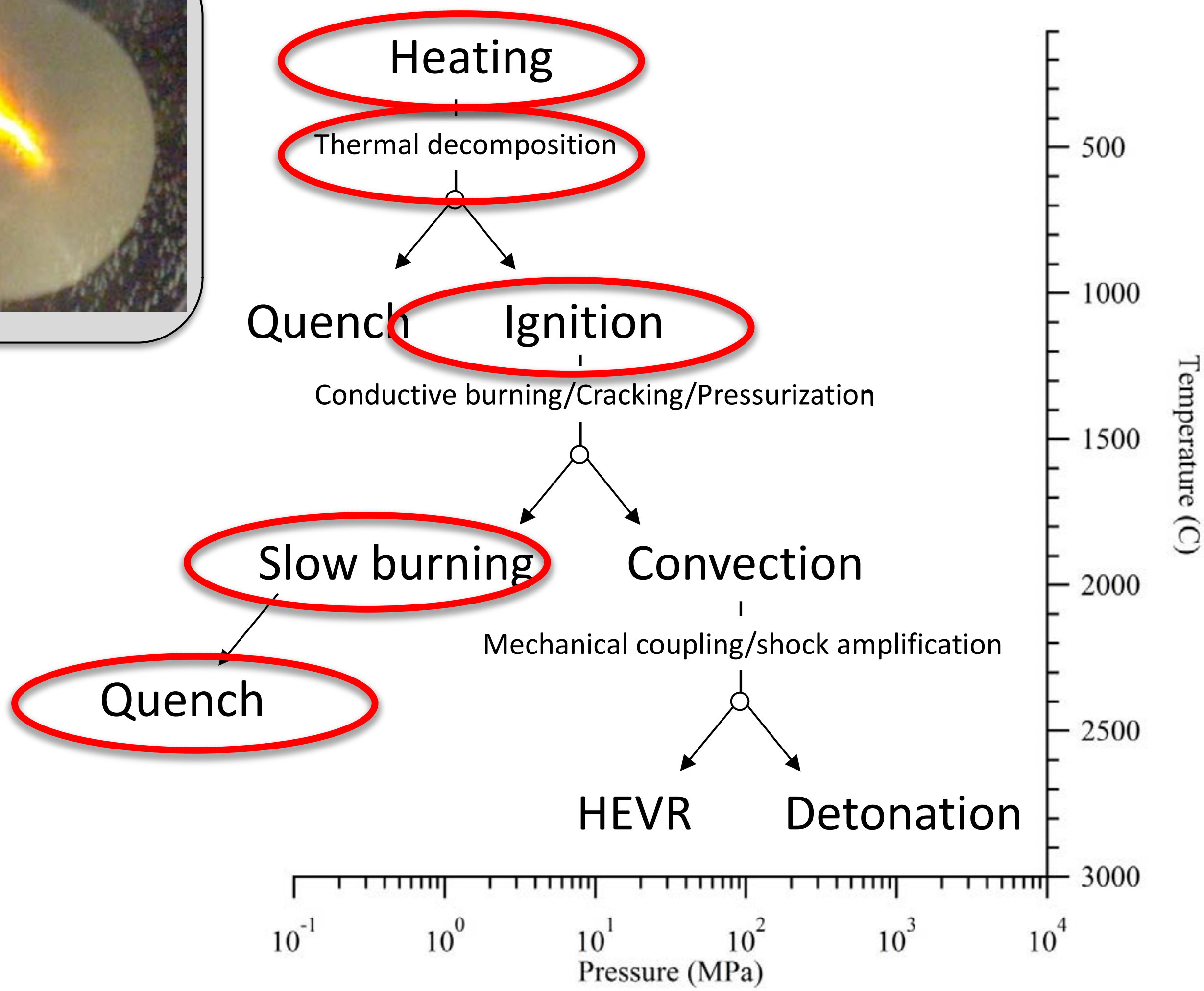
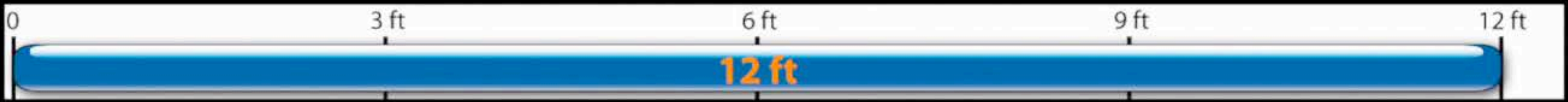




Skid Testing Drop 053A&B

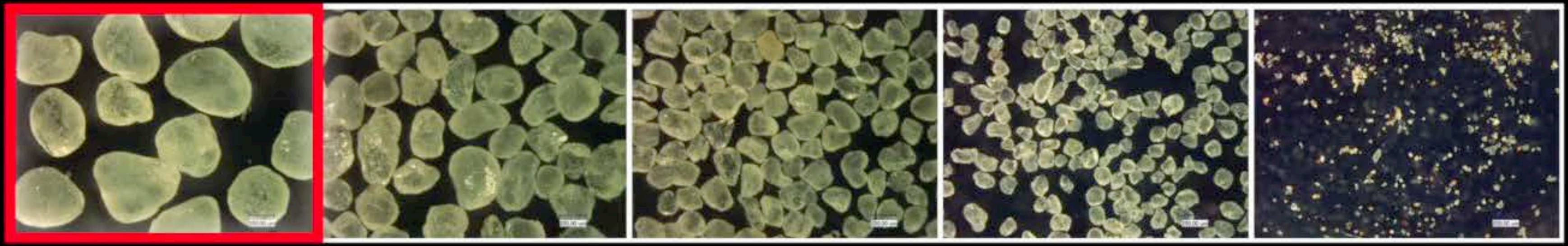
Nominal Height:



Material: PBX 9501

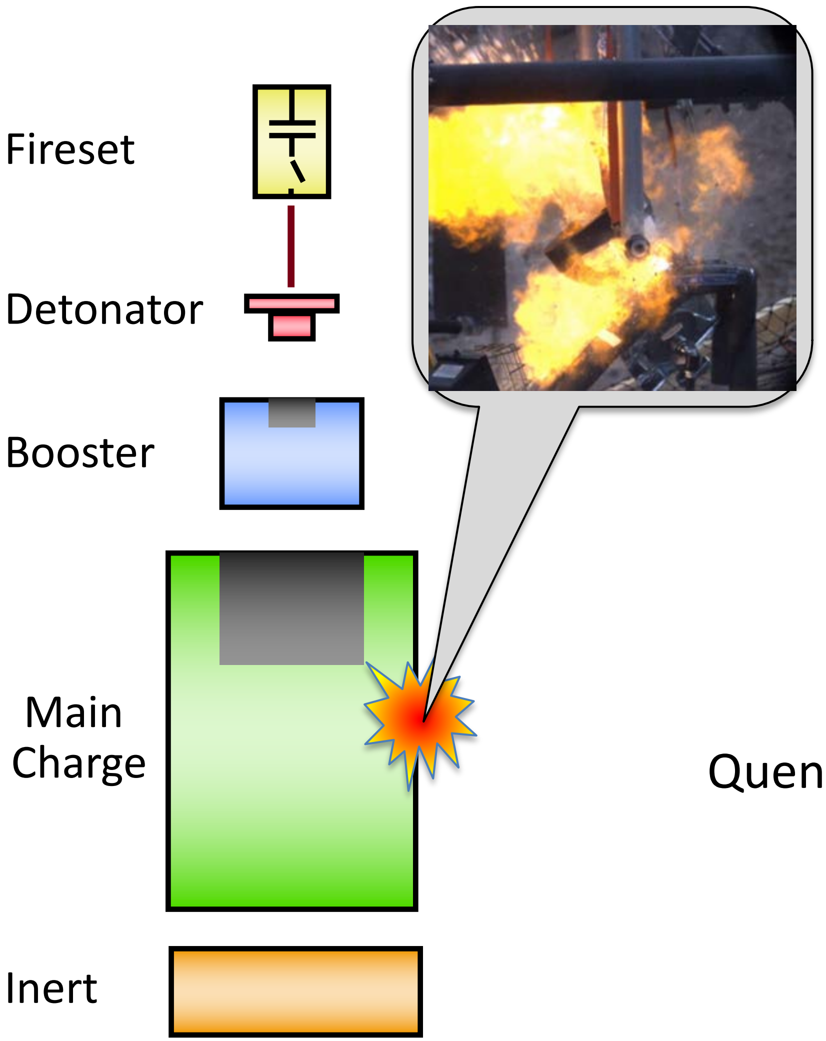
Impact Surface: steel

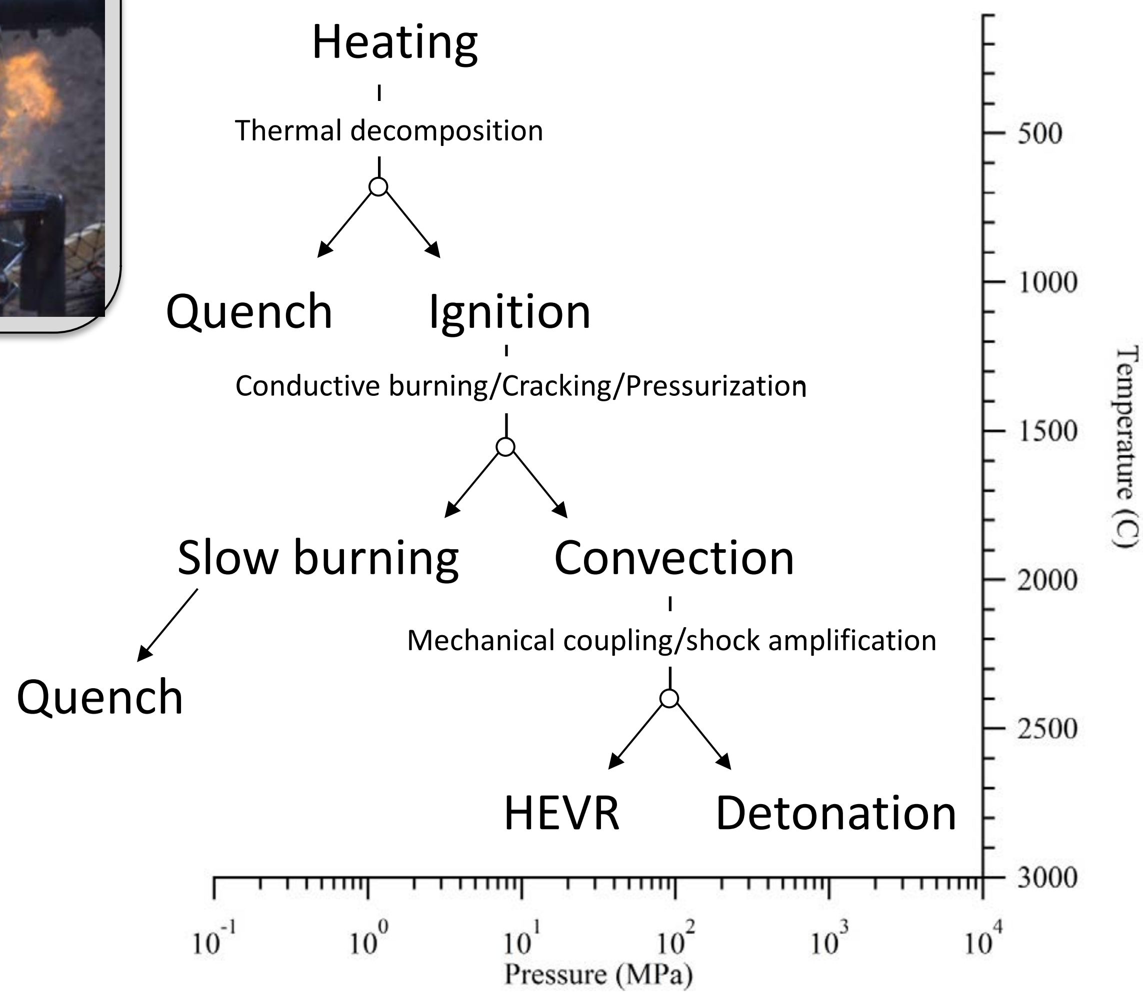
Grit: 500-1000 micron dia.



Notes: Random coverage. Example of highest violence response. Fireball.

What happened in this test?





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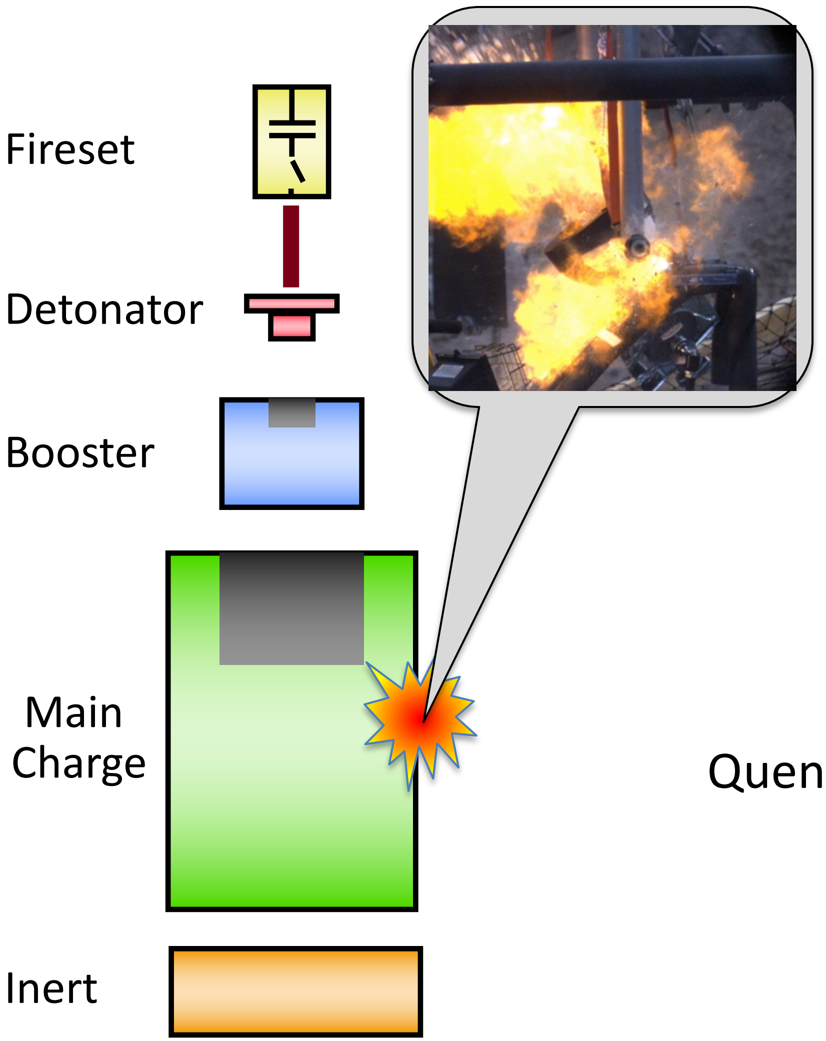
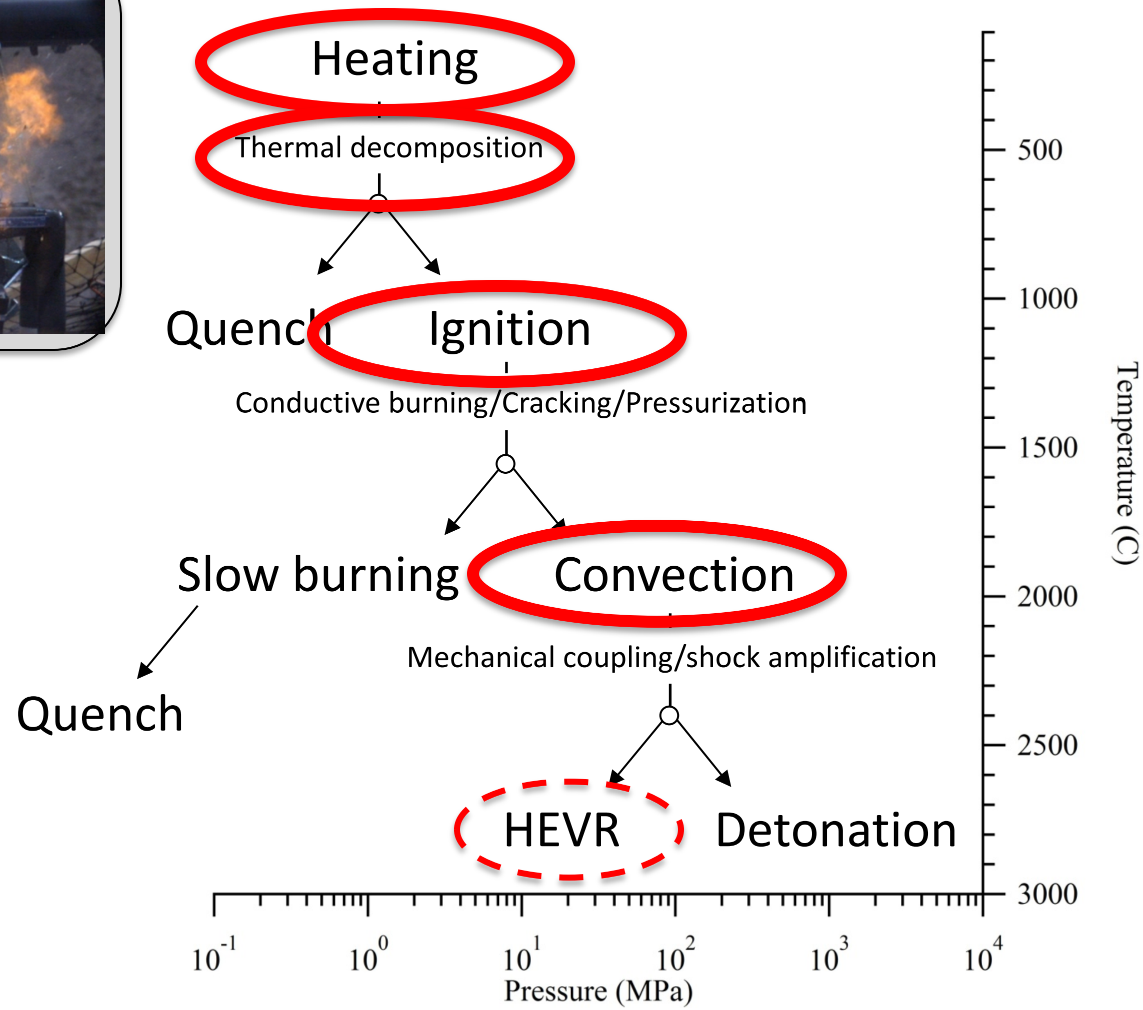


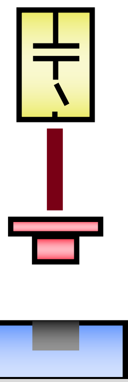


What happened in this test?

Fireset

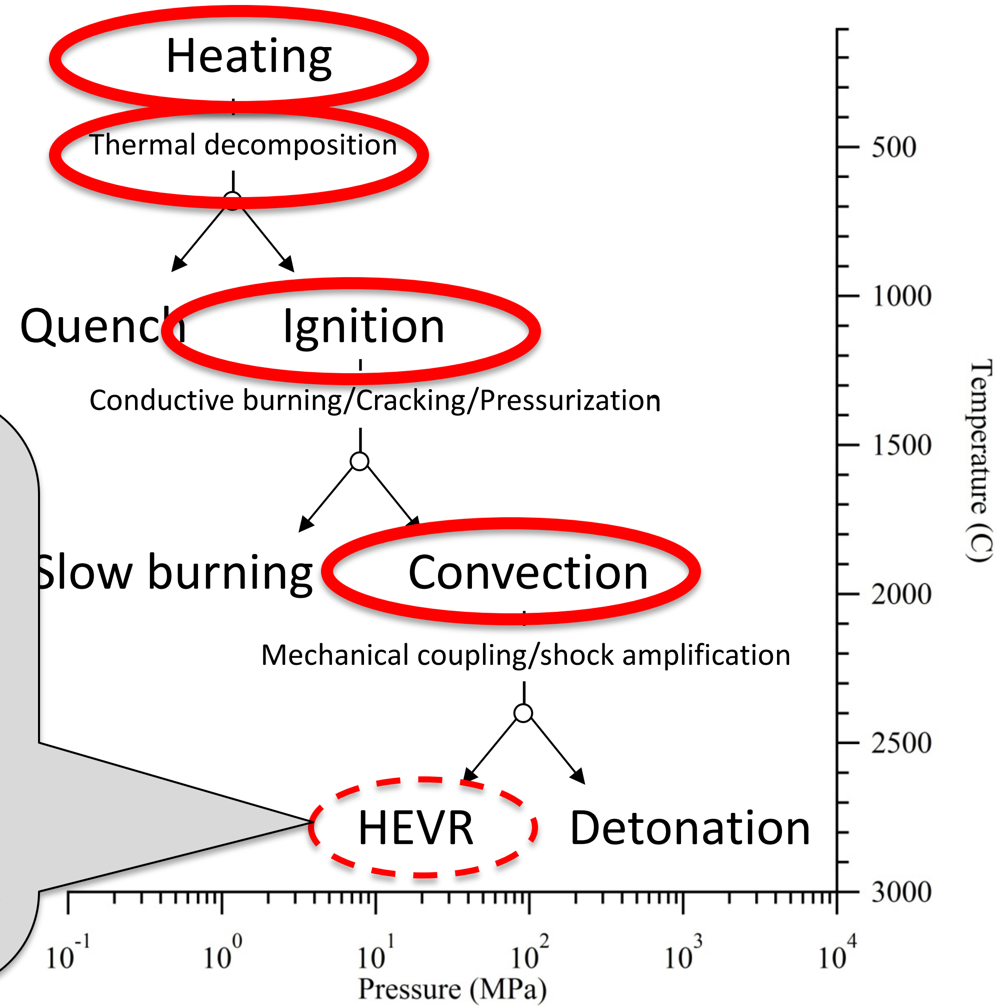
Detonator

Booster

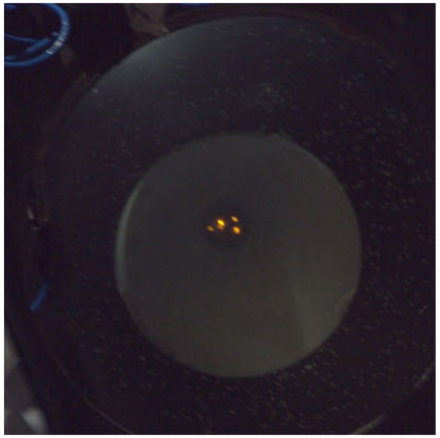


“For the purposes of the nuclear explosive and weapon surety directives, an HEVR includes reactions ranging from a fast deflagration of the High Explosive up to and including a detonation of the high explosive. The explosive wave may be subsonic or supersonic.”

- DOE O 452.1E



CHE Levels of Reaction



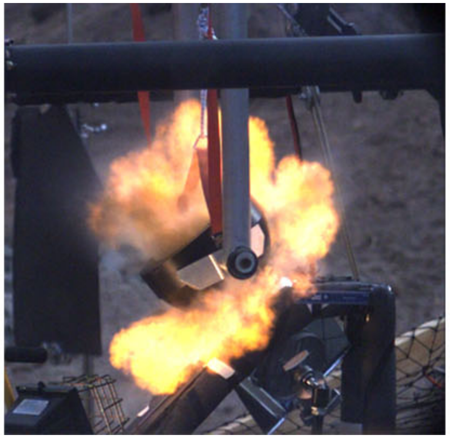
VISIBLE IGNITION SITES

Isolated ignition sites that do not coalesce and extinguish when the charge bounces

FLAME GROWTH INTO CRACKS

Multiple ignition sites that coalesce, with flame spread into cracks in the charge.

The ignition quenches before extensive propagation due to bounce or intersection of the cracks with the outside of the charge.



CRACK PRESSURIZATION

Flame spread into cracks causes sufficient pressurization to fragment the charge, leading to combustion of rubblized explosive.

This looks more significant than it is – only a few grams of explosive are consumed, with the remaining mass unreacted.

HEVR/DETONATION

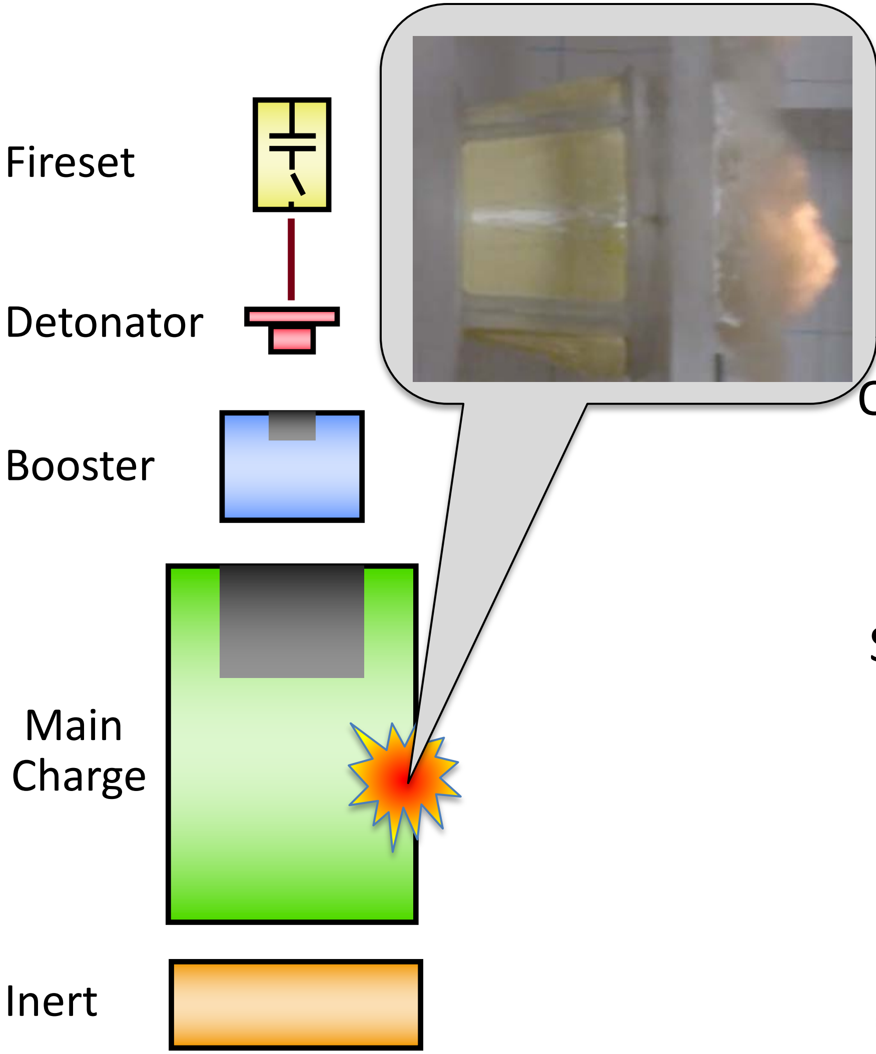
Flame spread into cracks leads to rapid pressurization and reaction buildup, with the inertial confinement of the charge mass sufficient to permit transition to a violent reaction.

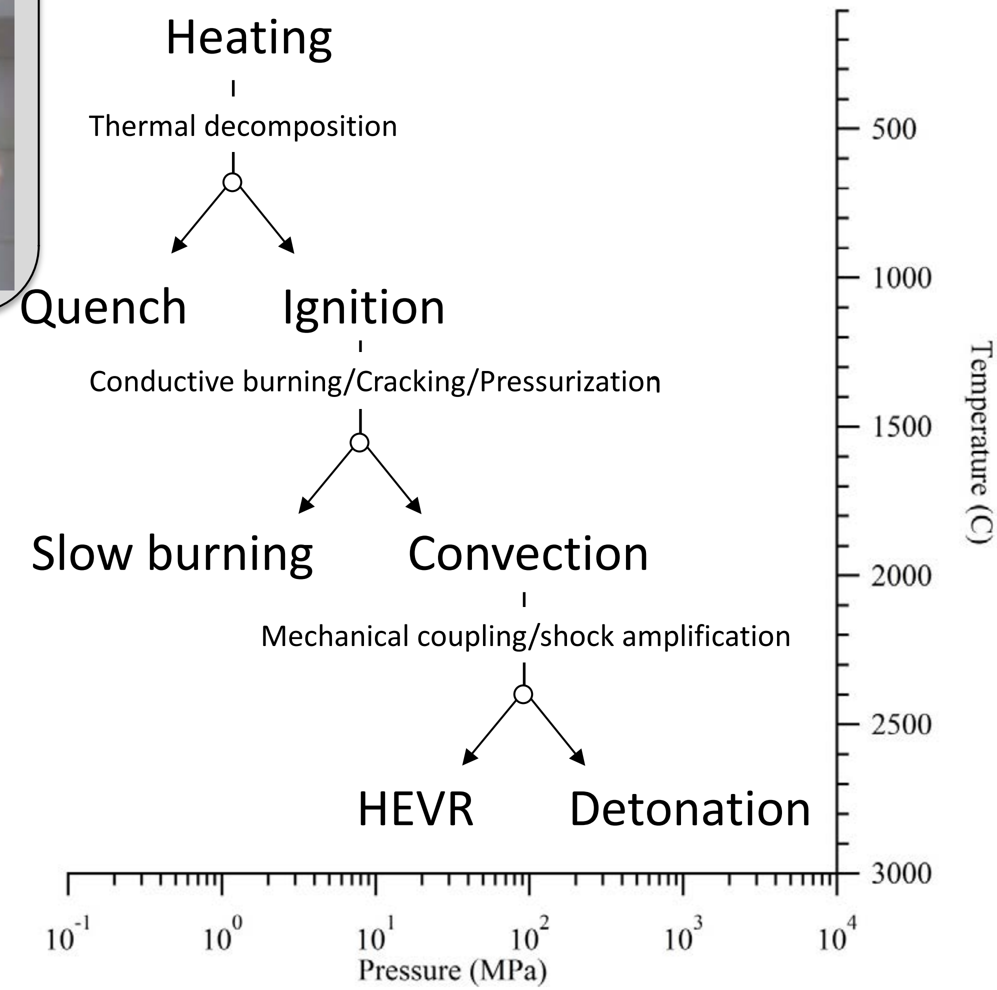
Most, or all, of the explosive is consumed. Transition to detonation may or may not occur, but local effects are extremely severe either way.

What happened in this test?

Projectile impact to IHE (720 m/s)

What happened in this test?





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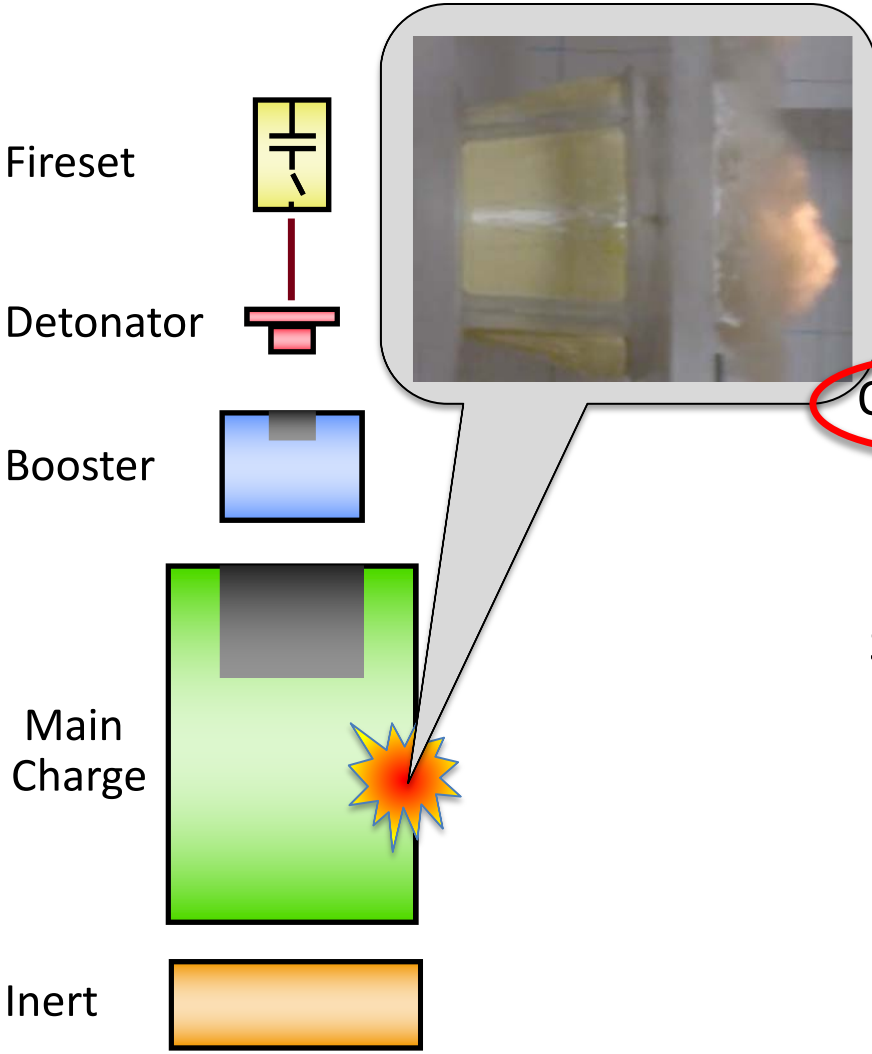
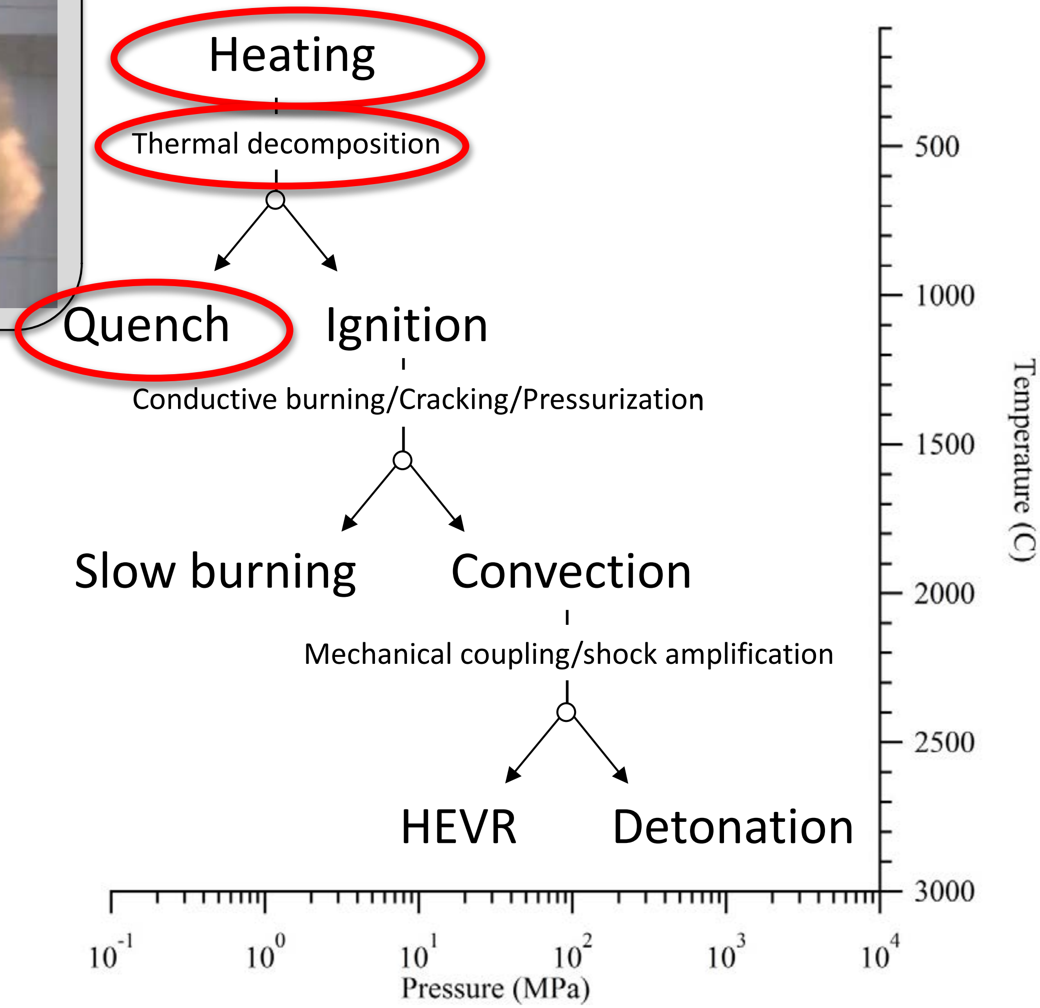
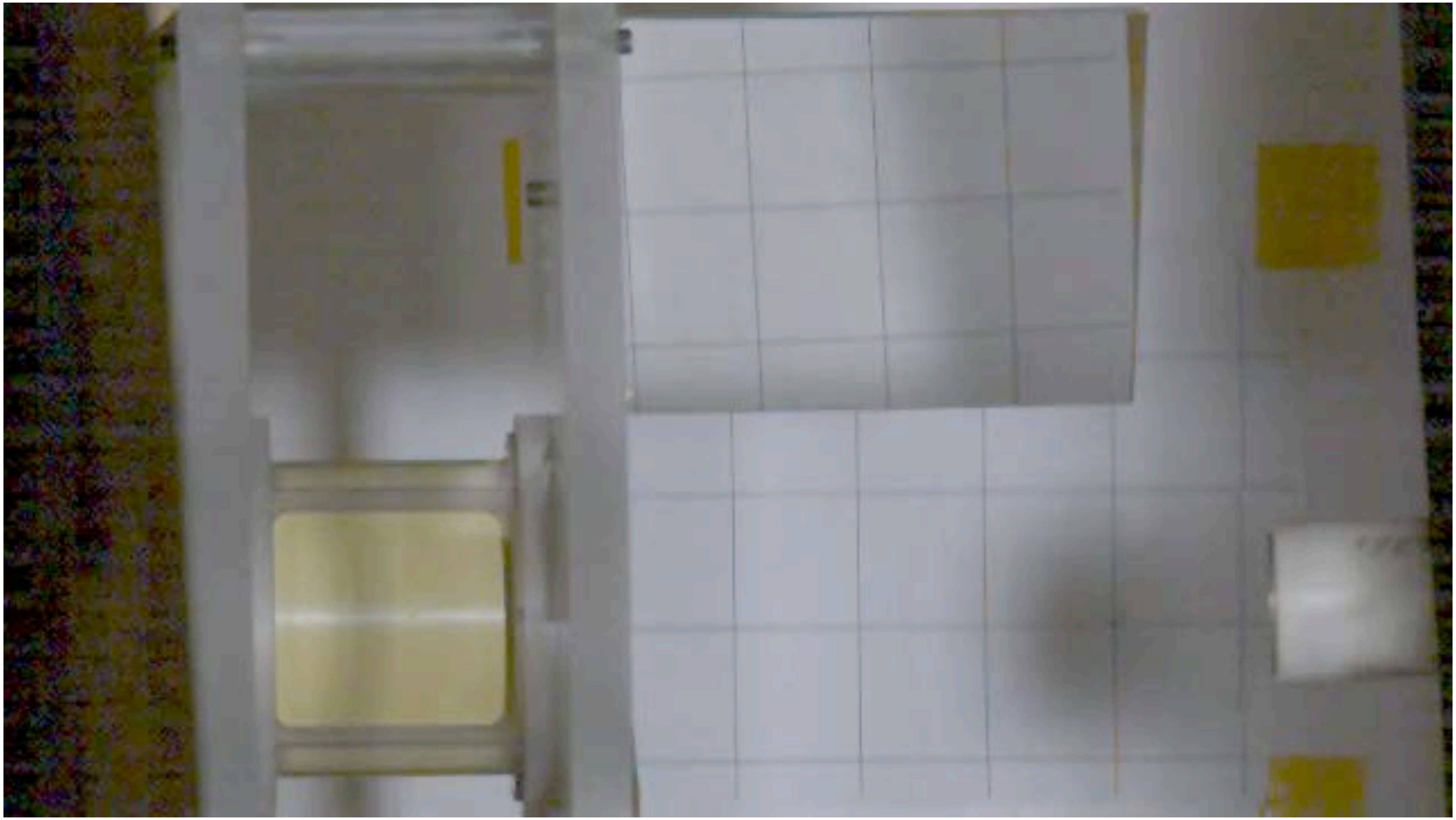


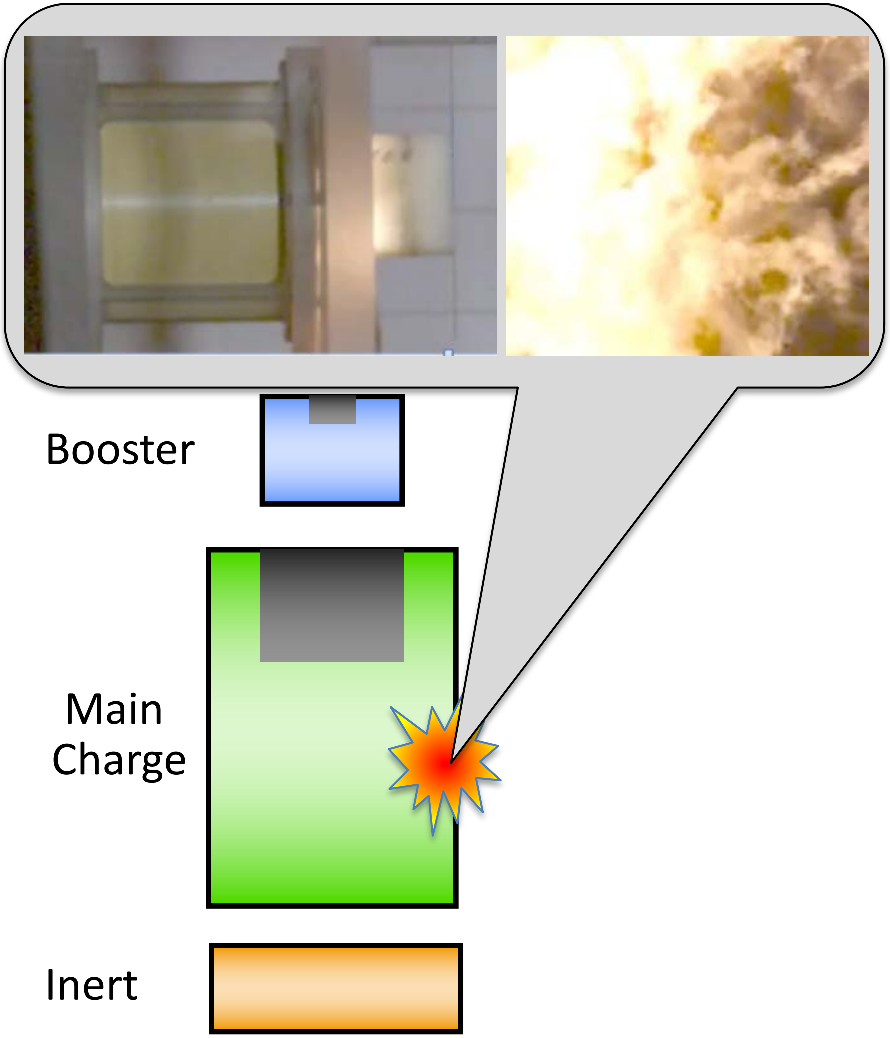


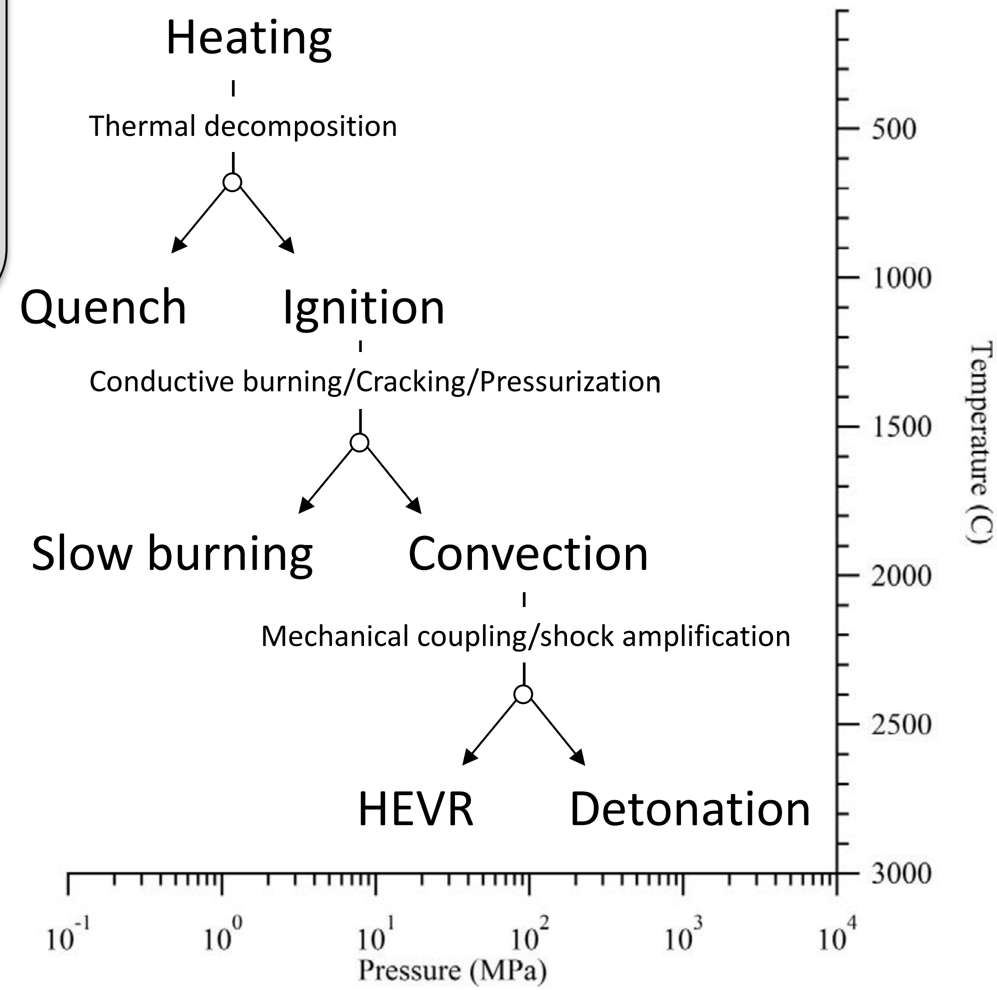
What happened in this test?

Projectile impact to IHE (760 m/s)



What happened in this test?





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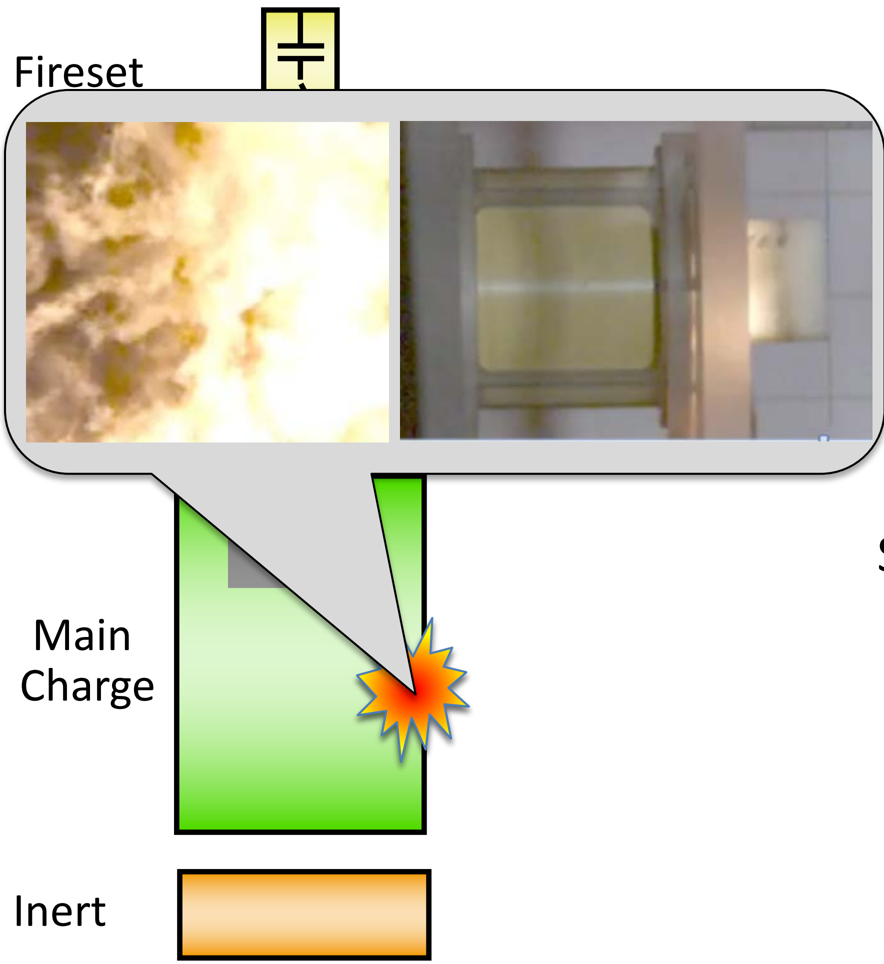

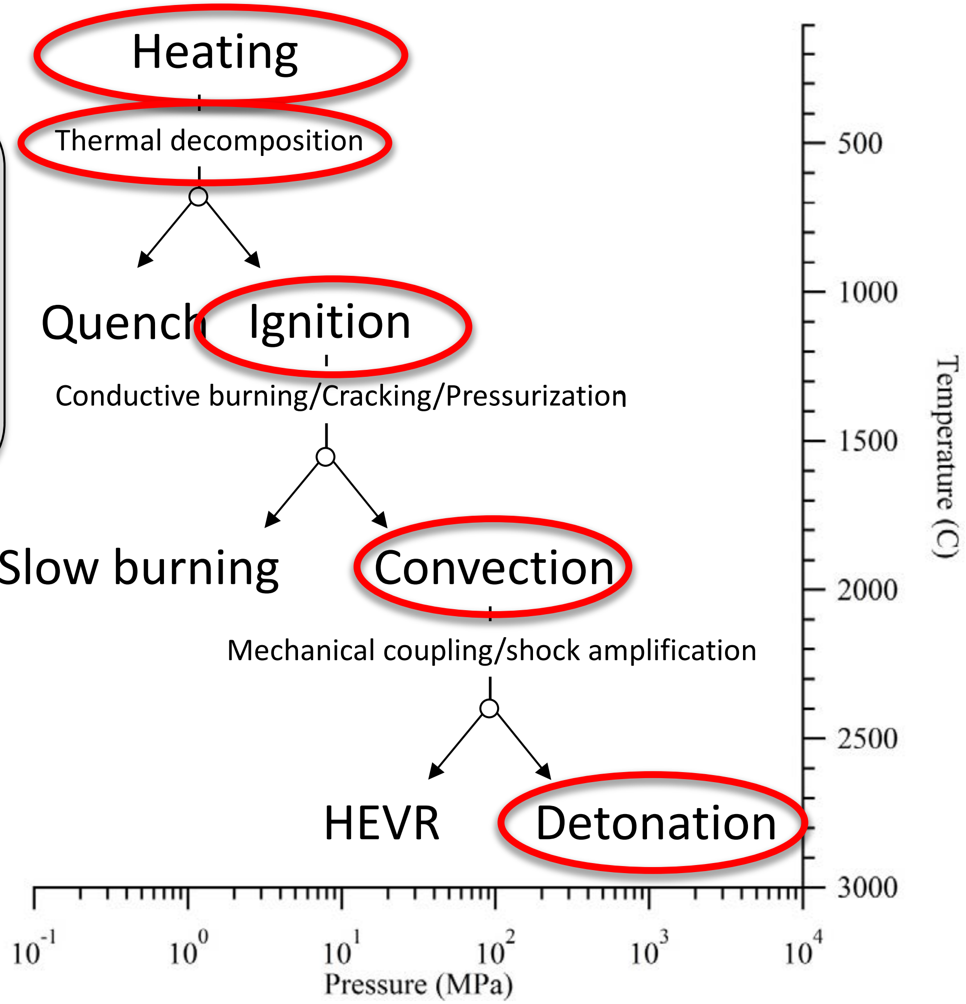

Final Exam

Where was the heat source?

June 26, 1956
Where was the heat source?

- June 26, 1956
- 50 pounds of explosives
  - New detonator material
  - Powder dried in oven
  - Distributed among 7 trays
  - Being scooped into jars
  - 4 trays had been emptied

June 26, 1956
Where was the heat source?

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  - New detonator material
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  - Being scooped into jars
  - 4 trays had been emptied
- **Suspected cause**
  - **Heat due to friction between metal scoop and metal tray**

Did we learn our lesson?

February 24, 1959
Where was the heat source?

- 7.5 pounds explosive
  - PBX 9404
  - Drilling small, deep hole
  - Had performed this operation many times before
  - Custom cooling bit

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  - **LANL and AWE have performed 100s of tests and never been able to repeat this outcome!**
- ***Suspected* cause**
  - **Plugged coolant channel**
  - **Broken drill bit**

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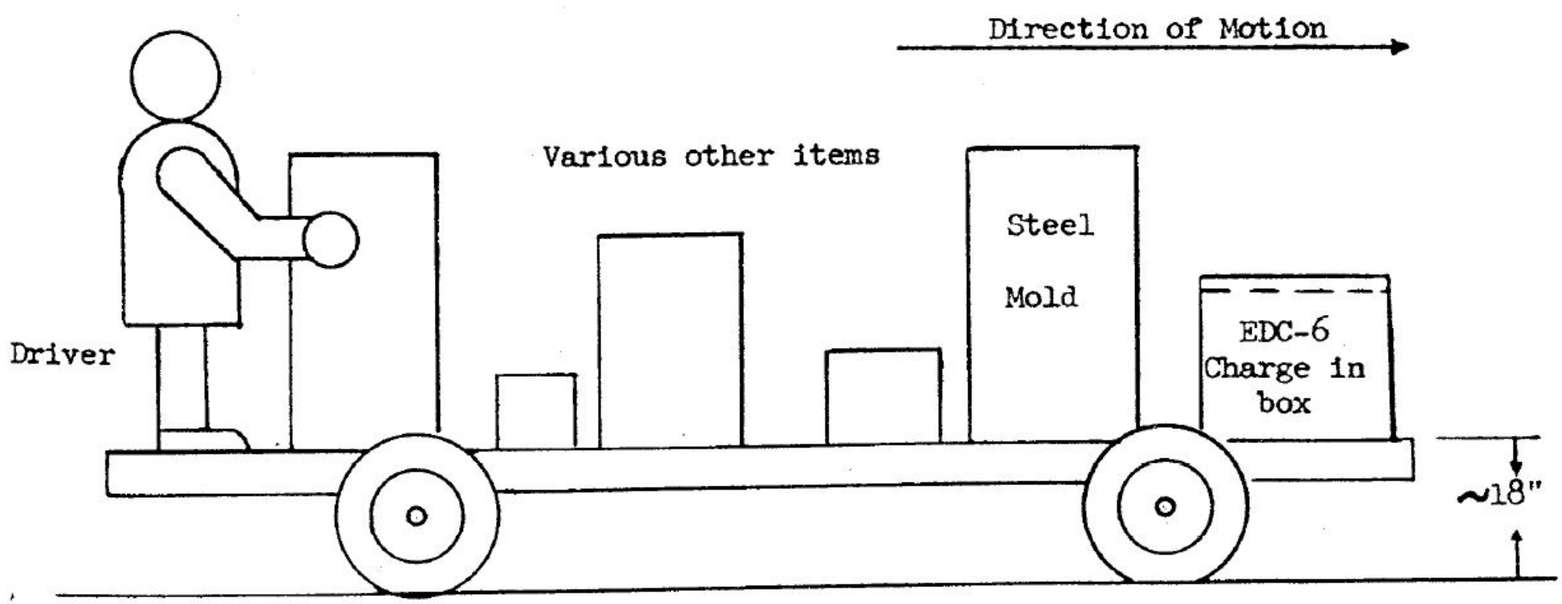
JUST BECAUSE WE'VE DONE IT 1000 TIMES BEFORE DOESN'T MEAN IT WON'T GO OFF THIS TIME

February 26, 1959
Where was the heat source?

- 49 pounds of explosive
  - Charge fell off bed of cart and out of wooden box onto the ground.



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Where was the heat source?

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  - Charge fell off bed of cart
- **Suspected cause**
  - **Drop/Impact of HE charge**
  - **Grit/Friction as the charge was picked up.**

Did we learn our lesson?

October 14, 1959
Where was the heat source?

- 300 pounds explosive
  - PBX 9404, very large piece
  - PBX 9010, machining chips
  - TNT- based scrap

October 14, 1959

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  - PBX 9010, machining chips
  - TNT- based scrap
- **Suspected cause**
  - **Drop of PBX 9404 piece**
  - **Impact to PBX 9010 chips**

November 13, 1963

- 123,000 pounds of High Explosive
- **Suspected cause**
  - **Sparking during an operation in the magazine**

May 4, 1988
Where was the heat source?

- Approximately 4,500 metric tons of Ammonium Perchlorate - Tertiary (Insensitive) Explosive
- After the Space Shuttle Challenger Accident, PEPCON continued to produce AP at a steady rate. Due to lack of demand, AP began to accumulate at their site in Henderson, NV.
- Due to a shortage of aluminum containers, PEPCON began storing AP in HDPE containers. HDPE can act as an oxidizer to some fuels.
- Some evidence suggests that there were multiple natural gas leaks from a line running directly under the plant.
- On May 4, 1988 a welding operation was reported as being performed near AP containers.
- Some witnesses indicated there may have been a sparking event near the HDPE containers just prior to the initial fire.

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Total of 5-7 explosions ranging from 40 lbs to 1kT (TNT equivalent).

Cause – undetermined

Potential causes

- **Nearby welding operations**
- **Potential natural gas leak**
- **Sparking during operations near the HDPE containers**

Extra Credit

Small Differences → Big Consequences

Be careful!

San Juanito (Mexico) Festival of the Exploding Hammers

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